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**AMERICAN PETROLEUM
SUPPLY AND DEMAND**

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THE AMERICAN PETROLEUM INSTITUTE

THE American Petroleum Institute was organized in 1919, an outgrowth of the activities of the National Petroleum War Service Committee, which service revealed the advisability and necessity of a permanent organization of this character. The Institute is an association of more than twenty-eight hundred persons engaged in the oil and allied industries. Membership is individual, and companies, as such, are not members.

The objects of the Institute as expressed in its charter are as follows:

- (a) To afford a means of co-operation with the Government in all matters of national concern; and
- (b) To foster foreign and domestic trade in American petroleum; and
- (c) To promote in general the interests of the petroleum industry in all its branches; and
- (d) To promote the mutual improvements of its members and the study of the arts and sciences connected with the petroleum industry.

PLAN OF ORGANIZATION

The general policies of the Institute are determined by the Board of Directors which at present is composed of fifty-three elective members, from all parts of the country. "Production" is represented on the Board by twelve members: "Manufacture" by ten members; "Distribution" by seven members; "Transportation" by three members; "Foreign Trade" by three members; "Equipment" by one member; "Natural Gasoline" by one member; "Natural Gas" by one member; and the industry "At Large" by fifteen members.

The principal departments are those for information and statistics, taxation and accounting, transportation, technical research, standardization and membership and finance.

AMERICAN PETROLEUM SUPPLY AND DEMAND

A REPORT TO THE BOARD OF DIRECTORS OF
THE AMERICAN PETROLEUM INSTITUTE BY
A COMMITTEE OF ELEVEN MEMBERS
OF THE BOARD

FIRST EDITION

SECOND IMPRESSION

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PART I

LETTER OF TRANSMITTAL
AND SUMMARY

AMERICAN PETROLEUM SUPPLY AND DEMAND

To the Board of Directors of the American Petroleum Institute:

In consequence of the creation by the President of the United States of the Federal Oil Conservation Board, for the purpose of making a study of the Nation's future supply of petroleum the Board of Directors of the American Petroleum Institute, having offered its co-operation to the Federal Oil Conservation Board, appointed from its members a Committee of Eleven to make an investigation of the oil industry and resources of the United States. The Board of Directors subsequently authorized the publication of the Committee's report, when completed, to the members of the Institute and to the Public.

The inquiry of the Committee of Eleven and the compilation of data and facts have taken some months to complete. The Committee believes that its work has been thorough and that the conclusions and opinions expressed are sound.

The survey has been countrywide, engaging not only the attention of a great number of operators, experts and scientists within the industry, with personal and first hand knowledge of conditions in the numerous oil-producing regions of the Nation, but also that of foremost experts in other matters which have a direct bearing on the future of oil.

The major factors of the investigation naturally concern the future supply of petroleum and the future demand of the country for petroleum products in time of peace or war.

For facts as to the future supply the Committee went to the industry itself, as best qualified through its knowledge and experience, for estimates of the volume of oil which

may be expected from existing fields, for prediction as to probable discoveries of new fields, and to experts in their given lines for statements as to the possible recovery of liquid fuels from the country's vast deposits of oil shale, coal and lignites.

To determine as accurately as possible what the future consumption will be the Committee obtained the calculations of authorities outside the industry on such vital topics as the future population of the country, its industrial growth, the probable increase, in consequence of such growth, in the number of automobiles and oil consuming engines, on the mechanical changes which will conserve oil through more efficient utilization, thus lessening the demand, and on other subjects having a direct bearing on the question of the volume of oil the American Public will require—estimated for a period of fifty years.

The American Oil Industry stands amongst the foremost of American industries. It is estimated that in its various branches—exploring, producing, refining, marketing and distributing—some 750,000 persons are employed and it represents an investment of more than nine billion dollars (\$9,000,000,000). The persons having investments in the oil industry number many hundreds of thousands. The industry performs a duty very important to national life and welfare and it is fitting that there should be placed before the Public some description of this peculiarly complicated business.

In its efforts to bring together and correlate the important facts about the industry and the future of petroleum, the Committee of Eleven has had constantly in mind the vital character of conclusions it might reach and has endeavored to be as conclusive as possible.

The Committee of Eleven is deeply indebted to a great number of persons, in the oil industry and outside of it, who have given the Committee much valuable assistance in its task of compiling this report.

Owing to the character of the industry the task of the

Committee has not been simple. The discovery of crude oil—which is the beginning of the oil industry and on which so much depends—is not an exact art. Oil is hidden—the industry is essentially a “finding” industry, attended with great uncertainties in the search. The future supply of crude oil cannot be blocked out and drawn upon as needed as in the case of oil shales, coal and lignites, from which liquid fuel can be extracted, and of many other minerals. Favorable looking lands become oil fields when the drill has revealed the presence of oil, and only then. Hence predictions of future supply of crude oil are necessarily conjectural. Speculative, also, perhaps to a greater degree, must be estimates of future demand, depending as they do upon conditions which, with the advance of science and invention, may undergo unforeseen and radical changes. Conclusions of the Committee are based on the best information obtainable, within and without the industry.

SUMMARY OF CONCLUSIONS

+ 1. There is no imminent danger of the exhaustion of the petroleum reserves of the United States.

2. It is reasonable to assume that a sufficient supply of oil will be available for national defense and for essential uses in the United States beyond the time when science will limit the demand by developing more efficient use of, or substitutes for, oil, or will displace its use as a source of power by harnessing a natural energy.

3. Current supply and demand cannot stay in balance, since the amount of both supply and demand are constantly changing. Generally, current supply will exceed or be less than current demand, creating surplus or shortage; either condition will be reflected in price, but price will in time correct either condition.

4. Petroleum recoverable by present methods of flowing and pumping from existing wells and acreage thus proven consist of five billion, three hundred million (5,300,000,000) barrels of crude oil.

5. It is estimated that after pumping and flowing there will remain in the area now producing and proved twenty-six billion (26,000,000,000) barrels of crude oil, a considerable portion of which can be recovered by improved and known processes such as flooding with water, the introduction of air and gas pressure and mining, when price justifies.

6. Improved methods of deep drilling below oil sands now producing will disclose in many areas deposits not hitherto available, which will be tantamount to the discovery of new fields. Improved methods of producing have been perfected which will make possible recovery of oil from these lower levels. The limit of deep drilling has not been reached.

7. The major oil reserves of the United States lie in some one billion, one hundred million (1,100,000,000) acres of lands underlain by sedimentary rocks, and not fully explored, in which geology indicates oil is possible. With extended search new supplies will be found therein.

8. The Nation has an additional reserve in the vast deposits of oil shale, coal and lignites from all of which liquid fuel and lubricants may be extracted if and when the cost of recovery is justified by the price of these products. These deposits are so huge that they promise, under conservative estimates, an almost unlimited supply.

9. While this report is confined to the petroleum supply and demand within continental United States the importance of imports cannot be ignored. Countries to the south are known to have large petroleum resources, for the output of which the United States is a natural market and the supply therefrom must inevitably have its influence on the consumption of American reserves.

10. The availability of future petroleum supplies from the vast area of land mentioned above depends upon adequate incentives to the exploration which in the past has given the Nation a sufficient supply of petroleum, in peace and in war, throughout the history of the oil industry, from its inception in 1859.

There must be:

- (a) Security in the ownership of oil lands and of the right to lease.
- (b) Conditions of exploration and development by owners or lessees permitting exercise of initiative, liberty of action, the play of competition and the free operation of the law of Supply and Demand.
- (c) Prices that will provide a return to producers, refiners, and distributors commensurate to the risks involved and the capital invested.

11. The supply of petroleum will be made to go much further through more efficient utilization. Automotive experts state that the mileage of the motor car per gallon of gasoline may be doubled through structural mechanical changes, when price justifies such changes. Improved mechanics will also result in smaller consumption of lubricants.

12. Through improved methods, principally the process known as "cracking," the refining branch of the industry has already increased the yield of gasoline, now the major product of petroleum. Through further improvements and extensions the supply of gasoline will be augmented still further by the "cracking" of fuel oil. In consequence the supply of fuel oil will be correspondingly diminished, thus eventually removing fuel oil from competition with coal.

13. Waste in the production, transportation, refining and distribution of petroleum and its products is negligible.

Respectfully submitted,

J. Edgar Pew, President, American Petroleum Institute, New York;
Vice-President, Sun Oil Company, Dallas, Texas.

E. W. Marland, President, Marland Oil Company, Ponca City, Oklahoma.

D. M. Folsom, Director, General Petroleum Corporation, San Francisco.

E. T. Wilson, Chairman of the Board, Continental Oil Company, Denver.

K. R. Kingsbury, President, Standard Oil Company (California), San Francisco.

George S. Davison, President, Gulf Refining Company, Pittsburgh.

W. S. Farish, President, Humble Oil & Refining Company, Houston.

J. C. Donnell, President, Ohio Oil Company, Findlay, Ohio.

W. N. Davis, President, Mid-Continent Oil & Gas Association; Vice-President, Phillips Petroleum Company, Bartlesville, Oklahoma.

Frank Haskell, President, Tidal Oil Company, New York.

R. L. Welch, General Secretary, American Petroleum Institute, New York.

STRUCTURE OF REPORT

Upon organization and study of the problem, the work of the Committee of Eleven was divided into three major classifications:

1. Growth and development of the American petroleum industry.
2. The future supply.
3. The future demand.

The Committee of Eleven was divided into sub-committees, each to report on a given topic.

The salient features of each subject are presented briefly in this summary which is followed by the full texts and the complete data from which conclusions have been drawn.

In assembling the material for this survey the facts and probabilities have been brought together through the co-operation of outstanding men engaged in the petroleum industry in all parts of the country—executives of lifelong experience in the production, refining, marketing and distribution of oil; and geologists, chemists and engineers. Authorities outside the industry have been freely consulted in regard to the probable growth of population of the Nation, industrial expansion, the development of hydro-electricity and the very important and apparently imminent improvement of the internal combustion engine which, it is estimated, will so increase mechanical efficiency as to reduce gasoline consumption per mile by almost one-half.

More than two hundred and fifty persons have contributed opinions and information to these reports. There have been meetings in all parts of the country where oil experts have gathered for debate and discussion of the various problems with a view to arriving at the soundest possible conclusions. The gathering of the data and the drafting of the report have taken nearly six months to complete.

SUMMARY OF THE "SUPPLY REPORT" *

The major phases of the report on Supply are as follows:

An estimate of a future production of more than five billion, three hundred million (5,300,000,000) barrels of oil from existing wells and from acreage these wells prove to be oil bearing, by present methods of flowing and pumping. This estimate was reached through detailed examination of the performance of every oil field in the United States:

An estimate that when pumping and flowing in present fields shall have ceased, there will remain twenty-six billion (26,000,000,000) barrels of oil, a considerable portion of which can be recovered through known methods, and a discussion of what has already been accomplished in this respect.

A discussion of the probability of the existence of undiscovered oil sands beneath existing oil fields, which improved methods of deep drilling have now placed within reach, and from which new oil supplies will be obtained:

A statement, arrived at after detailed study, that there are in the United States more than one billion, one hundred million, (1,100,000,000) acres of land of geological formation favorable to the presence of oil. Within this area new fields will be found. There are approximately 827,000,000 acres where oil is not possible:

An estimate that there are within the United States about three hundred and ninety-four billion (394,000,000,000) short tons of oil shale, from which about one hundred and eight billion (108,000,000,000) barrels of crude shale oil can be recovered, yielding twenty-five billion (25,000,000,000) barrels of motor fuel:

A minimum estimate of five hundred and twenty-five billion (525,000,000,000) barrels of liquid products from the country's deposits of coal, yielding an estimated ninety-two billion (92,000,000,000) barrels of motor fuel:

* The Supply Report appears in full beginning on page 37.

An estimated field of seventy billion (70,000,000,000) barrels of liquid products from the country's lignite deposits, twelve billion (12,000,000,000) barrels of which could be used as motor fuel:

A discussion of "waste" in the production of oil, and of present drilling practices and of methods of developing oil fields.

The Supply Committee of the Committee of Eleven does not undertake to forecast in specific terms a total future supply of crude oil, nor production by years. With respect to the volume of oil from existing wells and proven fields, an actual estimate—five billion, three hundred twenty-one million, four hundred twenty-seven thousand (5,321,427,000) barrels—is made, for here there are ascertainable facts, from a study of the various fields and from experience, on which to base the estimate of probable yield. So also with the oil which will remain in the ground when present fields have ceased to produce through flowing and pumping. Here again there are facts of experience at hand, and the estimate of twenty-six billion (26,000,000,000) barrels remaining is arrived at. This means that it is estimated that two barrels of oil will remain in the ground for each barrel previously produced. It is also possible to justify estimates of yields of liquid fuel from shale oil coal and lignites. But as to future production from the yet undiscovered oil fields the Supply Committee makes no estimate. The report says:

Due to the nature of the occurrence of petroleum and to the probability that the greatest part of our reserves is yet undiscovered, an estimate of this kind would necessitate an understanding of conditions which could not be brought to light even by the most careful survey possible over the entire United States.

The producing and proved area in the United States now totals 3,244,581 acres from which the present (week ending July 18, 1925) daily recovery is 2,115,000 barrels. The area within which oil may yet be found totals slightly over one billion, one hundred million (1,100,000,000) acres, while the geologically unfavorable area totals 827,790,000 acres

These figures justify the conclusion of the Committee on Supply that:

An estimate of reserves which are to come from fields yet to be discovered involves so many uncertainties that it would be grossly inaccurate and misleading.

The last general survey of the oil resources of the United States made in 1921 by the United States Geological Survey in co-operation with the American Association of Petroleum Geologists—a most thorough and painstaking effort—was proven within twelve months, despite the best efforts of the best minds available, to be a gross underestimate. The reserves of California from producing wells and proven areas were then estimated by the highest authorities at but little over half what they are now believed to be, and Oklahoma's reserves were understated in the light of present knowledge to the extent of 500,000,000 barrels.

RECOVERING OIL IN OLD FIELDS

While the Committee on Supply refuses to indulge in speculation as to the number of barrels of oil to be recovered from the one billion, one hundred million (1,100,000,000) acres within which oil may yet be found, its members have no hesitation in declaring that by recently adopted means of extraction, the now existing oil fields of the country can be made to yield "billions of barrels" of oil after flowing and pumping under present conditions have ceased. The Committee states that:

It is the general opinion of executives, engineers and geologists throughout the country that there will still remain in the ground, after all flowing and pumping have ceased, more than twenty-six billion (26,000,000,000) barrels of additional oil. With improved methods of recovery such as mining, flooding, the restoration of pressure, and other scientific methods yet to be devised, we believe a large proportion of this oil can be recovered from the present producing fields. The production of this oil, because of the nature of its occurrence, must necessarily be spread over a long period of years.

The new methods of recovery and the results obtained, are discussed at length in the Committee's report. It will suffice to state that in the Bradford field in Pennsylvania—where recovery is now secured by flooding the oil sands with water introduced from wells sunk into them and so flushing the petroleum into adjacent oil wells—Mr. Forest Dorn, whose name has been given to one of the methods of water treatment, states that the amount of oil recovered from producing areas which were nearing exhaustion as flowing or pumping wells, is as high as 10,000 to 12,000 barrels per acre. This is a much larger yield than other operators are securing and above the average that might be expected. From leases held by the Tide Water Oil Co., Mr. Frank Haskell estimates, on the basis of results already obtained, that 3300 barrels per acre will be recovered by flooding. All past production from these lands is estimated at 2600 barrels per acre. The amount of oil that will be recovered in the Bradford field by flooding with water—a process legalized so recently as 1920—is now estimated at 350,000,000 barrels. The Bradford sands, at points where analyses of cores were made by Mr. A. F. Melcher of the U. S. Bureau of Mines, are believed to have contained originally oil to the extent of 40,000 barrels per acre. During fifty years of pumping, and a relatively brief period of flooding, about 10,000 barrels per acre were recovered leaving 30,000 barrels per acre still in the sand. From the result of these experiments Mr. David White of the U. S. Geological Survey, speaking before the North Western Pennsylvania Oil Producers Association on October 28, 1924, estimated that two billion, five hundred million (2,500,000,000) barrels of oil still remain in the Bradford sands—a quantity almost a third as great as all the oil produced by the wells of the United States since 1859. The inference as to the oil content of new and prolific fields in other parts of the country cannot be ignored.

The cost of flooding is large, and the system cannot be operated economically on low-priced oil or land giving a meager yield.

OF GENERAL APPLICATION

It is held by some that the Bradford sands are unique, and that flooding cannot be applied successfully in most other sections of the country. The consensus of expert opinion is that the greater number of oil sands in the United States will respond to flooding in a satisfactory manner. Legislation will have to be passed by the various State legislatures before the system can be generally introduced. New York and Pennsylvania are now the only states where flooding of an oil sand is legalized. In areas where flooding is not practicable, because of the composition of the sands or the lack of water, the use of compressed air has been shown to give most satisfactory returns, while unwatering and mining—the latter as practised in Alsace—will also add greatly to the recovery of oil from areas that no longer produce by flowing or pumping. The general result of the application of these processes to oil production, it is estimated, will be the recovery from wells that have about reached the point of abandonment under the pumping system, and in which a fair pay-thickness of highly saturated sand still exists, of “billions of barrels” of oil that would have been lost to industry and the world’s wealth, but for the enterprise and efficiency of the petroleum producers of the United States.

A “BILLION ACRE” RESERVE

The Committee on Supply stresses the fact that the greatest of the national petroleum reserves consists of the one billion, one hundred million (1,100,000,000) acres of as yet unexplored and unproven land underlaid with sedimentary rocks that await the drill. Much evidence of a concrete sort is given that deep drilling in proven fields, and vigorous exploration in the “billion acre reserve,” will provide vast quantities of oil.

The element of uncertainty is not the existence of petroleum in the deeper levels of already proven areas and in the billion-acre tract still to be tested, but whether the price of crude oil will remain sufficiently remunerative to

warrant the investment of time and money in finding new oil fields. "Distress" crude must inevitably lessen the amount of exploration in progress at any particular time. Increasing prices, on the other hand, will bring their own corrective, as in the production of wheat or any other standard commodity, by stimulating production. And in the oil business from the very beginning the stimulation of production has depended far more upon the wild-catter in the field than upon any increase in volume that lessees of proven oil areas could secure from producing fields. Had it not been for a remarkable increase in the average initial flow of wells brought in by exploration during the past fifteen years, the increase of demand during that period, because of the tremendous development of the automotive industry, could not have been met.

Some of the more striking statements of the Committee concerning future possibilities are as follows:

PROBABLE NEW FIELDS

"The area in which new fields may be expected is of the same general character as the area which has produced and is producing our crude oil supply, and it has been tested much less thoroughly than has usually been necessary in the past for the development of new oil fields. With this great area to be explored, and with increased efficiency of exploration methods, additional oil fields will certainly be discovered.

OIL IN LOWER SANDS

"In every one of the producing areas of the United States oil will very probably be obtained in sands other than those now producing. Even in the Eastern fields, including the Appalachian District, where exploration has been active for more than half a century, it is reasonable to hope that new production will develop from some of the tests that are being drilled to deeper sands. In the Mid-Continent area, in Texas and the Gulf Coast, in the Rocky Mountain region, and in California, production is to be expected in many

fields in each of these subdivisions of the nation's petroleum reserves from sands other than those now yielding our oil."

SCIENTIFIC APPARATUS FOR DISCOVERY OF OIL

"The most notable progress in the application of new methods of discovery has been made in the past few years in the Gulf Coast area of Texas and Louisiana where the salt dome type of structure governs oil accumulation. Geophysical methods have been applied with notable success and it now appears that these methods will completely succeed the older methods of locating these structures. The discovery of three domes, Nash, Orchard and Long Point, in the Texas Gulf Coast region in 1924 by means of the torsion balance and the seismograph is the first result of exploration by geophysical methods. . . . With the thoughts of the various research departments turned toward mechanical means of locating underground structures, it is not beyond the realm of possibility that scientific apparatus will be perfected that will indicate the actual presence of oil."

Part II of the Supply Report deals with the huge deposits of oil shale, coal and lignites as a source of liquid fuel. The report indicates a virtually unlimited supply available, a total of four trillion (4,000,000,000,000) tons, with an estimated yield of liquid products of seven hundred billion (700,000,000,000) barrels, and of motor fuel one hundred and thirty-nine billion (139,000,000,000) barrels.

The Committee on Supply directs attention to the fact that these shale reserves are of special interest to the nation as a guarantee that oil fuel for the Navy will not fail. The report states that:

The Naval oil reserves were created in 1916 and from incomplete information it was estimated that each reserve was capable of producing somewhere near 500,000,000 barrels of oil. Subsequent studies by the U. S. Geological Survey and property owners in the immediate vicinity have proven that the Colorado reserve alone is capable of producing upwards of two billion five hundred million (2,500,000,000) barrels of oil—five times the original estimate.

NOT AN EXPERIMENT

The extraction of oil from shale has been carried on for many years in Scotland on a scale sufficiently large to give a yield averaging of late 1,200,000 barrels yearly used largely for illuminating purposes. The Scottish shale industry has furnished proof that a steady output of gasoline could be secured, were the need to arise, and the price to warrant, from the Rocky Mountain shales. The cost would be greater, perhaps materially greater, than that of crude petroleum from flowing wells, but there will be some offset from the carrying on of production and distillation as a continuous process.

WHAT COAL COULD ADD

The bituminous coal and lignite reserves of the United States were considered by the International Geological Congress in Ottawa in 1913. Estimating the best "reasonably possible" average recovery, based on the figures then accepted, it is believed that mining to a depth of 3,000 feet would produce two trillion, four hundred sixty-one billion, two hundred sixty million (2,461,260,000,000) tons. From this tonnage, so great as to become almost meaningless, the estimated maximum oil recovery would be two trillion, ninety-five billion, four hundred million (2,095,400,000,000) barrels and the minimum five hundred twenty-five billion, five hundred sixty million (525,560,000,000) barrels. The smallest estimate of the motor fuel recovery is ninety-two billion, ten million (92,010,000,000) barrels and the maximum three hundred ninety-two billion, six hundred forty million (392,640,000,000) barrels.

The practical value of the petroleum reserves contained in coal is materially lessened by the fact that the mining of coal for oil production alone would be a costly proceeding while the retorting of the entire tonnage of bituminous and lignite coal mined for general consumption in the United States in 1924—438,000,000 tons—would have produced

only 306,000,000 gallons of gasoline or barely three per cent of the total consumption.

The Committee on Supply is indebted to Horace C. Porter and to Ross H. Dickson for discussions on the production of liquid fuel from coal which appear in Section II of the Supply Report.

SUMMARY OF THE "DEMAND REPORT"*

The Demand Report forecasts what the country's requirements of petroleum products, and consequently crude oil, will be for a period of fifty years. The estimates are based primarily on a study of the growth of national population and national industry, with calculations as to the increase in automotive and other oil-consuming engines, with resultant increase in consumption, all leading to estimates of the total demand for oil, from decade to decade.

In making its forecast the Committee on Demand has approached the subject on two bases—a minimum demand and a maximum demand. The minimum demand estimated sets forth the amount of oil required to meet the country's requirements if, as is predicted will be the case, there occurs in the oil industry an extension of the refinery process of "cracking" crude oil, which produces a much higher yield of gasoline, and if, as automotive engineers declare is mechanically possible, the efficiency of the internal combustion engine is improved so as to bring greater mileage per gallon per motor car.

"Cracking" is already an established practice and its use is being rapidly extended throughout the oil industry. Further extension will vastly increase the yield of gasoline, now the major product of petroleum.

In response to a request for a statement on the possibility of increasing the mileage of motor cars through mechanical changes, C. F. Kettering, President of the General Motors Research Corporation, made the following reply:

We believe that it is possible to make automobiles go twice as far per gallon of gasoline used. The present internal combustion engine and automobile only transform an average of 5% of the energy originally in the gasoline into useful work. It is possible at present to transform 10% of this energy into useful work, and this will be common practice in the future.

* The full text of this report begins on page 167.

H. L. Horning, President of the Society of Automotive Engineers, addressing the American Petroleum Institute in December, 1923, said:

It is possible to double the miles per gallon of gasoline for cars and trucks. When the public want it they can go 40 miles per gallon on small cars.

Conservation.—In these two things, then, there lies the greatest field for conservation in oil. While the oil industry will produce more gasoline the automotive engineers will make the gasoline go much further through increased efficiency in utilization. At the same time, as the industry cuts deeper into the crude oil, extracting more gasoline, fuel oil will be sacrificed, and will thus, to a large extent, be removed from competition with coal.

The importance of the anticipated developments in the efficiency of utilization is seen in a comparison of the maximum and minimum demands, as shown by the Demand Report. For example, the maximum gasoline demand for 1950, based on there being no change in the motor car, will be 455,500,000 barrels, but under the minimum demand the requirements of 1950 will be only 227,700,000 barrels.

ECONOMIES OF REFINING

The conservation of petroleum supplies by "cracking" is already well advanced. By this process the heavier constituents of crude, such as kerosene and gas oil, are subjected to distillation at high temperature in special stills. The treatment breaks down or "cracks" a certain proportion of these heavier forms of oil into gasoline, leaving a correspondingly smaller residuum of heavy fuel oils or petroleum coke. The general adoption of this system of distillation would decrease to a marked extent the available supply of fuel oil and residue coke now available. The present yield of gasoline according to the Bureau of Mines' statistics is 33% of the crude run to stills. This could be increased to

55%. There is also a recovery of 25% of lubricants according to the Bureau of Mines.

The Committee on Demand believes that if improvements in refining and in automotive engines are adopted as foreshadowed, a petroleum supply would be required of less than 500,000,000 barrels in 1950, as compared with 643,966,000 barrels actually run to stills in 1924. There would be in addition from the operations of 1950 approximately 200,000,000 barrels of residue—or the equivalent in residue coke—from complete cracking methods. This should take care of about 30% of the estimated normal fuel oil demand of 641,000,000 barrels for that year, the balance to be taken care of from other sources, possibly oil shale or coal.

THE SHRINKING RESIDUE

This is an answer to the proposal that coal be substituted for fuel oil as a measure of conservation wherever possible. Twenty-five years hence, by improvement of automotive engines and refinery methods, the demand for crude petroleum may be reduced from 643,966,000 barrels to less than 500,000,000 barrels.

A NATION ON WHEELS

The phenomenal increase of automotive engines requiring gasoline will be the chief factor in bringing about this change. Figures compiled by the Committee on Demand, based on the formula of Raymond Pearl and Lowell J. Reed, of Johns Hopkins University, show the estimated total population of the United States by decades together with the number of families and of various classes of automotive engines. They indicate relatively rapid growth in all respects during the next 25 years, and a less marked rate of increase thereafter.

The increase in total population, families and automotive engines during the next quarter century is thus estimated:

	Population	Families	Automotive Engines *
1920	106,418,000	26,604,000	(1924) 18,028,000
1930	122,397,000	30,599,000	31,018,000
1940	136,318,000	34,080,000	39,755,000
1950	148,678,000	37,170,000	44,990,000

* Includes automobiles, motorcycles, aeroplanes, etc.

CARS FOR FOUR-PERSON FAMILIES

The number of families is obtained by dividing the population by four and it is estimated that by July, 1938, the number of passenger car registrations will equal the number of families. Passenger car registrations totalled 15,461,000 in 1924 and those of motor trucks 2,131,000. There were 436,000 motor boats, aeroplanes and motorcycles in use. The figures presented show an increase of passenger cars from 15,461,000 in 1924 to 27,400,000 in 1930, 34,000,000 in 1940 and 37,200,000 in 1950. Trucks are estimated at 3,000,000 in 1930; 4,700,000 in 1940, and 6,000,000 in 1950, a much greater ratio of growth than that of passenger cars. Motor boats, motorcycles and aeroplanes will, it is estimated, increase from 436,000 in 1924 to 618,000 in 1930; 975,000 in 1940, and 1,820,000 in 1950.

FUTURE DEMAND FOR GASOLINE

Having arrived at the probable number of automotive engines at various periods the Committee on Demand has found it comparatively easy to figure what the demand for gasoline would be in future years were there no marked fuel-saving improvements made in automotive engines. The gasoline consumption of the United States, according to Bureau of Mines' figures, increased from 75,000,000 barrels of 42 gallons in 1918 to 185,000,000 barrels in 1924. During the same period automotive engines increased from 6,500,000 to 18,000,000. The consumption of gasoline per car per year ranged from 11.13 barrels in 1918 to 9.67—the

lowest point reached—in the lean business year of 1921—when the increase in registrations also was less than in any other. Since 1921 the consumption has been 9.92 barrels per vehicle in 1922, 10.10 in 1923, and 10.15 in 1924. The seven years' average of 10.1 barrels has been adopted as that on which future maximum demand for gasoline may safely be based. Were this ratio of demand to remain constant until 1950 the gasoline called for in that year would total 455,549,000 barrels.

FUEL OIL CONSUMPTION

Due to a pronounced increase with a subsequent decrease in total consumption of fuel oil, gas oil and crude oil used for fuel in 1923 and 1924 respectively, it has been assumed that the consumption for these two years was of an abnormal character, so the 1920 and 1922 figures have been used by the Committee on Demand to determine the normal curve for the five-year period from 1920 to 1925. The total consumption in the United States during 1922, according to the estimate of the U.S.G.S., was 324,000,000 barrels. The Committee on Demand, basing its calculations upon official and trade reports, estimated that of this total, including Diesel oil, industrial and domestic consumption aggregated 228,000,000 barrels; railroads used 44,000,000 barrels; the merchant marine 32,000,000; the U. S. Navy 6,000,000, and public utility electric plants 14,000,000 barrels. Normal increase of this demand during the next twenty-five years would result in a fuel oil requirement of 641,000,000 barrels in 1950. The sub-committee makes no attempt to prove that such a demand could be met, contenting itself with stating that:

The demand for fuel oil has been approached from two angles; first by taking for granted that it would be forced by economic pressure to conform to the quantity of residuum left from the manufacture of gasoline and lubricants, and second by considering the predicted growth of industrial uses to which fuel oil is peculiarly adapted as a source of energy.

DIESEL ENGINE ECONOMICS

The general problem of conservation of fuel oil is considered in its relation to the various forms of use in locomotives, steamships, factories, on the farm and in the home, and the effect of gradual introduction of the Diesel engine is calculated. It is estimated that 15 per cent of the railroads in the United States are now electric, and that other types are converting to electricity at the rate of $3\frac{1}{2}$ per cent annually. Coal will continue to supply 90 per cent of this power, whether steam or electric, and fuel oil 10 per cent. Here again the Diesel engine, which operates by the burning in its combustion chamber of the entire content of crude oil, instead of by the explosion of vaporized gasoline, will be generally adopted, and will materially lessen oil consumption. By 1975 it is believed all locomotives will be electric.

Industrial establishments in 1919 used 93,000,000 barrels of fuel oil and 220,000,000 tons of coal. Where they cannot secure hydro-electric power it is believed that Diesel engines will replace 90 per cent of the present fuel oil equipment by 1975. The merchant ships of the United States burned 63 per cent fuel oil, 1 per cent Diesel oil, and 36 per cent coal in 1922. At the present time 57 per cent of all shipping under construction for U. S. owners is to be Diesel equipped. It is estimated that all fuel-oil burning vessels will be transformed to Diesel equipment at a rate that will result in a complete Diesel-driven merchant marine and Navy by 1965.

Of the result of the general adoption of the Diesel engine as a measure for the conservation of petroleum resources the Committee on Demand says:

This type of engine if successfully developed to take the place of our present popular gasoline engine by the elimination of excessive weight, flexibility in handling, etc., would have the effect of multiplying the available supplies of motor fuel six times, provided that the motor fuel being used was extracted from some form of crude. The popular gas engine now utilizes about 25 per cent of the crude whereas the Diesel engine would utilize 100 per cent of the crude,—and the gas engine has only approximately two-thirds of the thermal efficiency of a Diesel engine.

The economy of fuel consumption possible from the substitution of Diesel oil for oil fuel used under boilers has been illustrated by one of the vice-presidents of the Emergency Fleet Corporation who is on record as saying that a vessel equipped with Diesel engines will travel thrice as far on a given quantity of petroleum as a vessel in which the same quantity is burned under boilers to produce steam.

HYDRO-ELECTRIC POWER

The Committee on Demand has made a study of the possible extension of the use of the power of falling water for the development of electrical energy. It is stated that the total readily available generating capacity, according to the figures of the U.S.G.S. report for 1924, is 55,000,000 H.P. at 50 per cent efficiency or 35,000,000 at 90 per cent efficiency. The development of the hydro-electric power of the United States totalled about 10,000,000 H.P. in the period 1900-1925, and was "very slow" as compared to Canada, Norway, Japan and other countries. This was due to the low price of fuel, the remoteness of water power from great industrial centers, the lack of a nationwide network of transmission lines, and the difficulty of financing projects largely because of difficulty in obtaining satisfactory power-site concessions from Government. It is believed that during the quarter century 1925-50 because of growing cost of fuel, long distance transmission, and the work of the Federal Power Commission in providing satisfactory concessions, power development will proceed rapidly and perhaps 38,000,000 hydro-electric H.P. will be available at the end of the period.

Taking fuel oil at its minimum efficiency in the production of electric energy at the present time—3.4 barrels per 1000 H.P. hours—and assuming an annual operating average of 6,000 hours—public utility plants must supply current continuously—the estimated increase of fuel oil required if used to generate 28,000,000 additional electrical H.P. in 1950 would be 571,000,000 barrels yearly.

OPERATION OF THE OIL INDUSTRY

WASTE AND LOSS

It is the opinion of the Committee of Eleven that the Oil Industry has made and is making steady advance toward the elimination of all avoidable waste. A suggestion that the industry is conducted in a manner so wasteful as to be alarming is a matter of great concern to those engaged in it, who know by what ceaseless watchfulness has been brought about the reduction of physical wastage from oil well to consumer to a figure slightly over 3 per cent of the crude produced.*

Petroleum is particularly susceptible to natural losses, more so perhaps than any other major commodity in American industry. It is a liquid and as crude oil or as most petroleum products it is quite volatile. After crude oil is produced from the wells it is transported from the well to field storage, from field storage to tank farm, from tank farm to refinery, where it undergoes numerous processes and is transformed into products. After manufacture, gasoline is placed in steel storage tanks at refineries, from which it is drawn as needed and loaded into tank cars or tank ships and taken to points of consumption. Here again the gasoline is placed in storage to be removed as required and transported to points of consumption or sale, to consumers and to garages and service stations, in barrels or tank trucks. Once again the product is placed in storage, usually underground, to be removed by pumps, in small quantities as required. Between the well and the tank of a motor car, the product is handled probably 25 times.

INTENSIVE DRILLING

From time to time the industry is spotted with a spectacular development of new fields of oil, which, due to inten-

* A memorandum on "Losses" appears on page 242.

sive drilling and close spacing of wells, results in huge production, sometimes in a remarkably speedy manner. These spectacular events are largely responsible for a public impression of extravagance and waste in the oil industry. Whatever may be said of the expense of intensive and speedy development of an oil field, the result of competitive effort on the part of many producing units, as against a more orderly development under ideal but unattainable conditions, it can be said that avoidable waste of oil itself is nominal. In fact, most experts agree that in most fields intensive development with closely spaced wells will bring forth more oil than slowly developed fields with widely spaced wells, and there is much in the recorded performance of certain fields to indicate that this is true.

A brief description of the reasons for the spectacular development of some fields will be of interest.

THE RUSH FOR PRODUCTION

A "wildcat" well is often drilled in regions where property holdings are divided, sometimes into quite small plots, and when oil is discovered a condition which is known in the oil industry as "town lot drilling" ensues. When the "wildcat" becomes a producer, the owner of neighboring property naturally drills a well as quickly as possible in order that his property will not be drained by the first well. Other neighbors do likewise and there is a mad rush by perhaps scores of property owners within the now-proven field, to do likewise, and the field shortly presents a scene of terrific activity, with scores of wells being drilled. Pipe lines must be laid and storage facilities provided. The work goes on night and day. There is a great deal of competition and usually an appearance of confusion, which, not unnaturally, would give an impression of disorganization and consequent inefficiency and loss. But the fact remains that when the drills penetrate sands, and the gas pressure lifts the oil, perhaps in great volume, to the surface, the oil itself is turned into the pipe lines and safely sent to storage.

THE STORAGE PROBLEM

Frequently this intensive drilling and consequent speedy creation of a large supply of oil leads to a condition of surplus or over-production beyond the immediate needs of the consuming market, necessitating new storage, in the form of concrete lined reservoirs and steel tanks. In a recent work * on the oil industry it is stated that in California's oil fields during 1923 \$47,000,000 was spent on new storage.

The cost of this storage becomes a serious expense to the industry which would not have been incurred if there could be an ideal condition where the reserves of the earth could be turned on and off as needed, in strict accordance with the demand for crude oil. In this respect it might be said that it is an economic waste, but, as indicated, there is no waste of oil itself, for methods of handling and storage are now such that the natural losses through leakage and evaporation are nominal.

ECONOMIC LOSS IN DRILLING

The keen competition in drilling, particularly where the oil field is divided into small holdings, leads to the drilling of many wells until the field often presents an aspect of a forest of derricks. There has been a great deal of discussion on the subject of proper spacing of wells, i.e., how many wells per acre are required to recover the maximum amount of oil. In Part IV of the report on "Supply" this question is discussed by the sub-committee in charge of that study. The conclusion is reached that the closer the spacing of wells the greater will be the recovery of oil. In other words, theoretically an infinite number of wells would produce the maximum amount of oil. However, the question of the maximum number of wells to give the best economic result is raised and the answer to it varies with each particular field and depends on local conditions, such as the gas pres-

* Marcossion, *The Black Golconda*, Harper & Bros., 1924.

sure, thickness of the sands, depth, the drilling program, and the value of the oil itself.

THE PROBLEM OF GAS

Oil is brought to the surface by the pressure of gas, a valuable and useful product. In many cases the blowing off of considerable volume of gas into the air presents an aspect of loss of a useful product, but in most cases this loss is virtually unavoidable. A great quantity of the gas is saved, the proportion being largely dependent upon the adjacency of population providing a market. However, it is not always possible to sell all of the gas and it is impossible to place gas in storage. Hence there are losses of gas, but not until after the gas has served the very useful work of lifting the petroleum to the surface.

At the inception of a new field, even one favorably situated for the marketing of gas, a certain loss is inevitable. To save the gas and carry it to market requires the laying of pipe lines from field to city, which may be near-by or many miles away. The gas output of the first well, or even the first several, may not give the necessary evidence of volume and continued supply to justify the expenditure of large sums of money in construction of pipe lines. Pipe lines cannot be laid until there is reasonable assurance that the gas supply will prove large enough and long-lived enough to warrant the expense of such transportation facilities. Hence it is impossible to avoid losses until there has been a demonstration of the probable supply, a demonstration to be had only by actual performance.

The desire of producers to secure from gas all possible values is illustrated by the spread of the practice of "casing head" production of gasoline from wet gas. This form of securing the gasoline content of gas to the well-head was initiated in 1911 and 900,000,000 gallons of gasoline—1.4 for every barrel of crude produced—were thus recovered in 1924. Of existing oil reserves this natural gasoline, it is estimated,

will provide as much as would come from one billion (1,000,000,000) barrels of crude petroleum.

PAST PRODUCTION

Each decade since the beginning of the oil industry in 1859, has seen a volume of production equal to the total production throughout the whole previous history of the industry. During the last nine years (1916-1925) more oil has been produced in the United States than during the whole previous period—1859-1916. As the demand has grown, “wild-catters” of the industry, through vigorous prospecting, have succeeded in finding new fields, and the national supply has never failed in peace or in war, although there have been times of scarcity and anxiety. There is no known replacement for petroleum withdrawn from the earth. New supplies must be discovered in new places. A successful search for new oil either at depth in already-proven and operating fields or in hitherto unexplored areas will in all probability be no less difficult than in the past and assuredly not less expensive. For the extension of manufacturing facilities to take from the crude a greater volume of the higher products—a transition already well under way—vast sums of new capital will be required. If ever the Nation is obliged to turn to shales or coal for liquid fuels hundreds of millions of dollars will be needed for new equipment. The normal laws governing trade will control future prices, just as in the past the industry has been controlled by the economic law of supply and demand.

How successfully conducted it has been, in the large, is proven by the fact that from the soil of the United States there is taken year by year seven-tenths of the billion barrels of oil produced throughout the world and that American petroleum products in some form or other provide one of the largest classes of exports to foreign markets.

GROWTH AND DEVELOPMENT OF THE OIL INDUSTRY

The records of industrial development and changing social conditions in modern civilization set forth nothing else so dramatic as the evolutionary progress wrought in a single generation by oil and the automotive engine. Without the internal combustion engine, petroleum in the United States would have remained a "poor relation" struggling for a living against a growing development of electric light. Without gasoline as a cheap and available fuel the motor car and the aeroplane would have been costly toys and the greatest system of roadways the world has seen would have remained unimproved and in a large measure unfit for travel during several months every spring and fall. The recreative and educative influences of travel would have been unavailable for millions of men, women and children.

EARLY METHODS OF TRANSPORTATION

When Paul Revere rode out to arouse the Minute Men the swiftest means of transportation at man's command were a galloping horse and a ship sailing free before a favorable wind; the only effective power-producing appliances, the windmill and the water-wheel. There had been no change of moment in thousands of years. The United States existed as a nation for fifty years before the locomotive challenged the supremacy of the galloping horse. It is exactly a century since Stephenson's "railway for steam locomotives" was opened between Stockton and Darlington in England. The limit of speed was supposed to be six miles per hour and it was arranged that to ensure public safety a man on horseback should ride on the track ahead of the engine to warn of its approach by carrying a flag.

DAYS OF DISCOVERY

In the same year Faraday discovered that benzine was a constituent of petroleum. Seven years earlier the first flowing oil well in the United States had been drilled accidentally at the mouth of Troublesome Creek on the south fork of the Cumberland River by Martin Beatty who was seeking brine. During the next forty years petroleum as a by-product of salt wells was obtained in considerable quantities and was used for medicinal purposes and as an illuminant.

It was not until the spring of 1859 that George Bissell, a business man of New Haven, Conn., on behalf of a syndicate formed in that city to search for oil at Titusville, Penn., engaged Colonel Edwin Drake to carry on the work of boring. Oil was struck at a depth of $69\frac{1}{2}$ feet on August 23 after drilling operations that lasted six months and became the jest of the countryside. Drake's claim to fame rests upon the fact that he was the first man to drill for oil with steam power through rock and to operate the world's initial cased oil well. By 1869, ten years after the Titusville discovery, the annual production of petroleum had risen to 4,215,000 barrels of 42 gallons, and kerosene had driven sperm oil out of general use.

THE LIGHTING PERIOD

Upon this foundation of illuminating oil the petroleum industry of the United States grew in magnitude and efficiency until it became one of the major industries of the country. American well-drillers carried to the principal oil fields of the world the methods developed in Pennsylvania and Ohio. American tank cars and pipe lines were copied by rival producers abroad. The machinery of production and distribution evolved by the pioneers of the United States became the standard wherever oil was sought or handled. The high degree of efficiency attained was due largely to the fact that the oil pioneers occupied an untrodden

field and that in the search for petroleum and in the adaptation of methods for bringing it into general use the keenest powers of reason and intuition were perforce enlisted.

THE AGE OF GASOLINE

Until the development of the internal combustion engine there was unavoidable waste of gasoline, the most volatile of the derivatives from the crude oil and that which is now most in demand. Gasoline began to come to its own when in 1883 Daimler, following the principle established by Lenoir, Roches and Otto during several decades of experimentation, built the first high-speed internal combustion engine. The vital difference between Daimler's engine and those of his forerunners was that he used petrol and they used gas. In 1886 Daimler applied the new power to a motorcycle and in 1887 to a self-propelled carriage. Shortly thereafter the operators of American refineries ceased to dispose of gasoline by draining it into handy water-courses.

A STUPENDOUS GROWTH

No general statements as to the growth of the petroleum industry in the United States during the 66 years that have passed since Colonel Drake struck oil can be more impressive than the figures presented in the reports herewith attached.

From the beginning of production 658,029 wells have been drilled in the United States. Of these 133,435 were failures, 228,447 were either gas wells or oil wells that have ceased to produce. There remain 296,147 producing oil wells. The Report on Supply includes a tabular statement showing that to March 31, 1925, seven billion, eight hundred seventy-one million (7,871,000,000) barrels of crude oil in round figures had been produced in the United States. The Report estimates after careful investigation that the remaining productive wells or the areas which they prove beyond reasonable doubt as available for future production con-

tain reserves recoverable by flowing or by pumping totaling five billion, three hundred twenty-one million (5,321,000,000) barrels. The wells now producing, constitute 56 per cent of all wells put down since 1859 which were originally productive, but in most cases the yield is of greatly diminished volume as compared with the initial flow or early yield. Under pumping, Pennsylvania's 76,664 wells yield a daily total average of only 20,628 barrels. Adding to the seven billion, eight hundred seventy-one million (7,871,000,000) barrels already produced the five billion, three hundred twenty-one million (5,321,000,000) of reserves recoverable by flowing or pumping it is estimated that the ultimate production, by these methods, of wells now in operation and of areas proven by them will total thirteen billion, one hundred ninety-two million (13,192,000,000) barrels. In addition it is believed that casing-head production of gasoline from wet gas will yield as much gasoline as could be obtained from a billion barrels of crude.

THE EARLY PRODUCERS

The persistence of production is indicated by the fact that in Pennsylvania, Ohio and West Virginia, the states in which the oil industry was first established, there are still 135,201 producing wells drawing from an area of 805,000 acres, less than a fortieth of the acreage within these states in which geological conditions indicate that oil fields may be found. The yield of these 805,000 acres has been one billion, six hundred twenty-five million (1,625,000,000) barrels and it is believed that from the producing wells upon them there will be a further recovery of 233,000,000 barrels by flowing and pumping.

LEADING PRODUCING AREAS

Oklahoma, Texas and California, the great producers of the present, have only 86,563 wells in operation, but they have already yielded four billion, six hundred forty-nine

million (4,649,000,000) barrels by flowing and pumping from 599,147 acres. These states have the vast area of 223,940,000 acres of land, within which oil may yet be found and 750,303 acres of proved but undeveloped oil lands. In other words, there are in Oklahoma, California and Texas geological indications that oil may be found over an area comprising one-ninth of the total land surface of the United States.

HOW PRICE OPERATES

The problem of obtaining a sufficient supply of oil to meet the demand has always been one of economics; of price performing its normal function of increasing or decreasing production or consumption—and there has been nothing in the fluctuations of prices or in their general level up to this date to suggest physical exhaustion of supply, requiring the use of substitutes or the employment of revolutionary methods of consumption. This has remained true notwithstanding the fact that no one has ever known how much oil there is in the ground, where it is, or when, or at what rate it will be brought forth. Through the mere functioning of price the world, without great difficulty, has increased its production in 25 years from 150,000,000 barrels per year to approximately one billion (1,000,000,000) barrels per year. The United States production in 1900 was 63,620,000 barrels; in 1924, 714,000,000 barrels.

REAL PRICES VERY STEADY

The sub-committee bases its conclusion that price and demand have been the dominant factors in bringing about the growth and development of the industry in the following recital of facts: In 1913 the number of automobiles registered in the United States first passed the one million mark. The domestic production of oil in that year was 248,446,000 barrels. The average price of Mid-Continent crude oil was 93.4 cents per barrel. The demand for gasoline from motor vehicles was approximately 10,000,000 barrels. In

1924 the domestic production of crude was 714,000,000 barrels; the gasoline demand 214,000,000 barrels from 16,000,000 motor vehicles, and the price of Oklahoma-Kansas crude oil according to the United States Bureau of Labor Statistics was \$1.45 per barrel. On April 2, 1925, it was \$1.938 per barrel. Making due allowance for the change since 1913 in the purchasing power of the dollar, the average value of Mid-Continent crude oil in 1924 was \$0.967 per barrel, and the value on April 2, 1925, was only \$1.08 per barrel.

On the same basis, that is making allowance for the change in the purchasing power of the dollar, the highest value ever commanded by Mid-Continent crude was \$1.50 per barrel during 1920. In 1913 the base price for gasoline was 16.8 cents per gallon. Allowing for the change in the purchasing price of the dollar, the average price in 1924 was equivalent to 12 cents in terms of 1913 values, and is now—April 2, 1925—13.1 cents or 22 per cent below its exchange value in 1913. The value of gasoline, therefore, as measured in the quantities of other staple products that could be secured in exchange was lower in the last quarter of 1924 than at any other time since the automobile became an important factor in the lives of the people of the United States. These facts of record show how little the frequently-reiterated prophecies of failing supplies affected prices during the period when many men of eminence in the scientific world predicted "certain decline" of production. These prophecies and estimates were "purely speculative," and subsequent events proved them to be unwarranted.

There has not been a time from 1859 to the present when the oil industry has had in sight a supply which in and of itself assured the meeting of the future demand over a protracted period. The oil industry has ever been, and still is, an industry founded upon "finding." The finding of the past has been accomplished by individual initiative, by the free movement of oil prices, and by the influx of new capital.

EXHIBIT A

The following letter from the President of the Institute was transmitted to the Federal Oil Conservation Board:

Washington, D. C.
January 16, 1925.

HON. HUBERT WORK,
Federal Oil Conservation Board,
Washington, D. C.

Dear Sir:

I hand you herewith copy of a resolution adopted by the board of directors of the American Petroleum Institute on January 13th. I am requested also to assure the Federal Oil Conservation Board that the American Petroleum Institute is very desirous of assisting it in this inquiry in every possible way. We have appointed a committee to study the whole situation thoroughly and to ascertain the facts. This committee will take pleasure in co-operating with your board.

Because of the scope and importance of the questions submitted in your recent letter to a number of the Institute's directors and others, it will take some time to secure the data which would be necessary to answer them. It is the judgment of our committee that these questions cannot be answered satisfactorily to your board or to the petroleum industry without a full investigation of all the available facts. The committee has already begun its work and will complete it as promptly as possible.

Very respectfully,

J. EDGAR PEW,
President, American Petroleum Institute.

The Board of Directors of the American Petroleum Institute met in Atlantic City in January and adopted the following resolution which the President of the Institute enclosed with the above letter:

Whereas, The President of the United States on December 19, 1924, created a Federal Oil Conservation Board, consisting of the Secretaries of War, Navy, Interior, and Commerce, to study the government's respon-

sibility with regard to the conservation of oil, and to enlist the co-operation of representatives of the oil industry in its investigation; and

Whereas, The American Petroleum Institute wishes to record its approval of the principle of co-operation between government and industry, and its desire to co-operate with the conservation board; and

Whereas, A full and intelligent discussion of the problems involved and collaboration on the part of the industry necessitate the collection and exhaustive study of many facts not readily available in order that the Institute may present constructive policies and avoid immature recommendations or unwise experiments;

Now, Therefore, Be It Resolved: That the president of the Institute be requested to offer to the Federal Oil Conservation Board the cordial co-operation of the American Petroleum Institute.

Be It Further Resolved: That the president of the Institute be and is hereby authorized to appoint a committee of eleven (11) members, consisting of its president and general secretary *ex-officio*, and nine (9) other members of the Institute, with power to appoint sub-committees, to collect the facts; to study the problems pertinent thereto, and to report its conclusions and recommendations to the board of directors of the American Petroleum Institute at a future meeting for its consideration and action; and

Be It Further Resolved: That the committee be requested to seek the views and co-operation of all branches of the industry.

PART II

REPORT ON THE FUTURE SUPPLY OF
PETROLEUM IN THE UNITED STATES

SECTION 1. PETROLEUM FROM WELLS

REPORT ON THE FUTURE SUPPLY OF PETROLEUM IN THE UNITED STATES

The Report on Supply has been prepared by a sub-committee consisting of Wallace E. Pratt of Houston, Chairman, G. C. Gester, San Francisco, E. W. McCrary, Tulsa, and F. Park Geyer, Ponca City, from the opinions, data and conclusions as set out in the several technical sub-committee reports presented by the following technical sub-committees from each particular section of the country:

- DISTRICT: Pacific and Rocky Mountain States.
Committee..... G. C. Gester, Chairman,
C. R. McCollom,
C. J. Hares.
- DISTRICT..... Texas, Louisiana, Arkansas and Mississippi.
Committee..... Wallace E. Pratt, Chairman,
W. B. Pyron,
Alexander Deussen.
- DISTRICT..... Oklahoma, Kansas and Northern Mid-Continent
States, together with Kentucky, Tennessee and the
Southeastern States.
Committee..... F. Park Geyer, Chairman,
James H. Gardner,
J. Melville Sands.
- DISTRICT..... Eastern and Middle Western States.
Committee..... E. W. McCrary, Chairman,
R. S. McFarland.

In the preparation of this report the work of assembling the information from these technical committee reports was divided among the members of these several committees. Each member was given that part of the study with which he is most familiar. These subjects thus treated were then assembled into the following report by the first-named sub-committee.

Each of the technical sub-committees prepared a report which brought together the ideas of the best minds in the industry in the particular section which it represented.

The work of the technical sub-committees in each case was directed along two general lines: First, an inquiry into the nation's reserves of petroleum for the future. Second, an analysis of the best thought throughout the industry as to the efficacy of present methods of petroleum production, particularly with reference to waste of oil and gas and to probable relative recoveries of petroleum by the prevailing practice of rapid, complete exploitation of each pool, as compared with a program of deferred development spread over a period of years following discovery. On the question of petroleum reserves, the sub-committees have brought to bear the accumulated data and experience of leading petroleum geologists through the nation; while on the subject of recovery methods and practices the sub-committees have obtained and presented the composite opinion of hundreds of petroleum executives, superintendents and engineers throughout the industry.

This report, then, should embrace the composite opinions, data and conclusions of the petroleum industry concerning the supply of petroleum and the manner in which this supply is being recovered over the entire United States. Like the reports of the sub-committees which it combines, the general report considers the question of petroleum reserves first, and then presents an analysis of production methods and practices. A summary of findings and conclusions on both investigations makes up the first part of the report, to which the supporting data are appended in greater detail.

The discussion of oil left in the ground after pumping and flowing cease, and the possible recovery of this oil, forms the third and last section of the report. The Committee is unwilling to set up as definite reserves this large quantity of oil left in the ground, although it feels confident that a large part of this oil will be recovered if future demand ever justifies the cost of extraction.

SUMMARY OF FINDINGS AND CONCLUSIONS

PETROLEUM RESERVES

Character of Estimated Reserves.—The sub-committee believes that the free petroleum reserve of the nation includes first, oil to be recovered by present flowing and pumping methods from known producing and proven acreage; second, casing-head gasoline from known producing and proven acreage; third, oil remaining in the ground in known producing and proven fields after flowing and pumping cease; fourth, oil and casing-head gasoline to come from deeper oil-bearing sands, not now producing, but known to be present beneath our present producing and proven areas; fifth, oil and casing-head gasoline to come from new fields and new producing districts, yet to be discovered in the large area in which new oil fields may logically be sought; and, sixth, oil which will remain in the ground under the fields yet to be discovered after flowing and pumping cease there.

Estimates of Petroleum Reserves.—In attempting to arrive at conclusions regarding the potential supply of petroleum in this country, an estimate of this supply in barrels would be ideal. However, due to the nature of the occurrence of petroleum, and to the probability that a large part of our reserves is yet undiscovered, an estimate of this kind would necessitate an understanding of conditions which could not be brought about even by the most careful survey possible.

At the beginning of this study the Committee on Supply believed that a reasonably accurate estimate of the oil to come from proven but undrilled properties and from wells now producing could be made, but that an estimate of reserves which are to come from fields yet to be discovered involved so many uncertainties as to be grossly inaccurate and misleading. This would result in a complete misun-

derstanding of our potential petroleum supply both in the minds of the public and of those men engaged in the industry who are not familiar with the methods necessarily employed in arriving at such estimates.

A large number of executives, operators and geologists were questioned on this subject, and their opinion was found to be almost unanimously in accordance with that of the Committee. A few believe that such estimates may be of some value if properly interpreted, but that when such estimates are made no assurance can be had that this proper interpretation will go along with the figures set out. The record of past estimates, which includes this class of reserves, is shown on a chart on page 44. This history alone is enough to demonstrate the futility of such an attempt. From it one might logically conclude that the more oil we take out of the ground, the larger our reserves become, since for the past ten years, in the face of our constantly mounting production, each successive estimate has shown increasingly larger reserves.

Day's Analysis.—In 1908, David T. Day, while Chief Geologist of the United States Geological Survey, made the first attempt in the direction of an exhaustive analysis of our probable petroleum reserves. Ralph Arnold, in 1914, made a careful survey and estimate. The United States Geological Survey, in 1915, issued a revised estimate to include new fields not provided for in Day's estimate. In 1918, David White, then Chief Geologist of the United States Geological Survey, published a further revision of previous figures. Lastly, the United States Geological Survey and the American Association of Petroleum Geologists, jointly in 1921, contributed an elaborately studied forecast.

Day, in his estimate fixed a minimum of eight billion, fourteen million, eight hundred sixty-four thousand, one hundred eighty-two (8,014,864,182) barrels and a maximum of twenty-two billion, five hundred fourteen million, eight hundred sixty-four thousand, one hundred eighty-two

(22,514,864,182) barrels. For error he allowed a latitude of 280%. At the end of 1923 the prolific and expanding Mid-Continent Field, in the light of his minimum figures, had already passed its goal and had become "exhausted."

Although Arnold's measurement of the country's future oil wealth was made as late as 1914, it will require, at the rate of production obtaining in 1924, less than two years more to produce all the oil which he allotted to our nation. In the light of his estimate, Kansas, Kentucky, Tennessee, Louisiana, and Texas all have been "exhausted."

The gauge made in 1918 by White, with but a continuance of the present rate of production, will be fulfilled in a trifle more than four and one-half years.

The 1921 Survey.—The last and most painstaking gauge or estimate of the nation's oil reserves, as stated, was made in 1921. The object being to make a thorough and comprehensive measurement, the United States Geological Survey invited the American Association of Petroleum Geologists to cooperate with it. This organization accepted the invitation, and leading geologists among its members in each of the producing districts in the United States were assigned the task of cooperating with the Survey in a review of the producing, probable and possible oil territory, and in the compilation of an estimate of the petroleum remaining in the ground and recoverable by present methods. Accordingly, such geologists invoked the assistance of other members of their profession and drew up estimates for their respective districts. The Survey assembled the reports from the various districts and combined them with reports made by its own members. Discrepancies and conflicting views were harmonized. This estimate gave the entire United States a reserve of nine billion, one hundred fifty million (9,150,000,000) barrels.

How Recoveries Compare with Estimates.—Perhaps it is in order to cite a few manifest underestimates in this compilation. Theretofore, California had produced one billion, four hundred twenty-seven million, three hundred eighty-

three thousand (1,427,383,000) barrels. It was allotted a total future production of one billion eight hundred fifty million (1,850,000,000) barrels. Since 1921 it has produced 650,000,000 barrels. At last year's rate of output, it will require but a little more than five and one-half years to produce the remaining one billion, two hundred million (1,200,000,000) barrels. To-day the oil to be recovered from present producing wells and proven areas yet un-

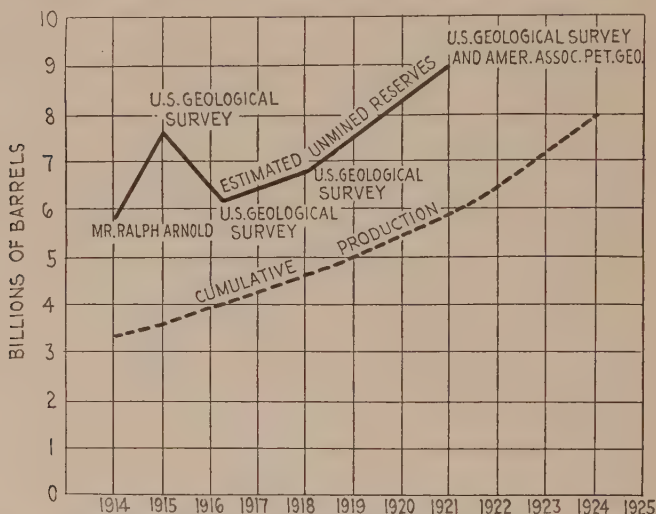


Plate A.—Estimated Unmined Petroleum Reserves and Cumulative Production.

drilled is estimated at two billion one hundred forty million (2,140,000,000) barrels.

Oklahoma had produced one billion, one hundred fifty-nine million, seventy-one thousand (1,159,071,000) barrels. It was allotted one billion, three hundred forty million (1,340,000,000) barrels for the future. Since 1921, it has produced 481,395,000 barrels, or the equivalent of 35% of such estimated reserves. During the past three years the state's average annual output has been 160,465,000 barrels. At this rate, a fraction more than five years yet is required to produce the remaining 858,605,000 barrels of its estimated recoverable oil. To-day's estimate of oil to come

from wells now drilled, and from areas proven for production, allowing no production at all for new discoveries, is one billion, three hundred fifty-three million (1,353,000,000) barrels.

Before 1922, the entire United States had produced five billion, nine hundred two million (5,902,000,000) barrels. Its remaining recoverable oil was fixed at nine billion, one hundred fifty million (9,150,000,000) barrels. During the interim of three years, it has yielded one billion, nine hundred seventy million (1,970,000,000) barrels. According to last year's rate of output, but little over ten years more will be required to fulfill and satisfy entirely such estimate.

The several estimates cited and reviewed probably are as dependable as our knowledge and the condition of the industry at the time would permit. In the estimate made in 1921, beyond question, more care, study, and probably more competent talent was employed than in the combined former estimates. Perhaps the selection of the estimators, as well as the methods employed, could not have been improved upon. In truth, in an estimate made to-day, substantially the same methods must be employed, for they are the best known to the industry. As indicated, the misleading character of this 1921 compilation is neither the fault of the estimators nor of the methods necessarily used. The estimate represents the best judgment of perhaps the best minds, and, as estimates of its character go, is entitled to respectful consideration. However, but twelve months were required to disclose that, in several details, it was clearly and grossly inaccurate.

Extent of Unexplored Territory.—The extent of present oil-producing or proven areas is comparatively small, whereas, the extent of the unexplored, but possible, oil territory is so large that it is impossible even for the best-informed students to make an intelligent guess as to the number of oil-producing acres it embraces, to say nothing of barrels of oil it may produce. Oil is a concealed or hidden mineral resource. Outside of producing and proven areas, no

method has been found, except exploration with the drill, to determine the presence or absence of petroleum, much less the amount which may exist. Obviously, in these circumstances and at this time, it is beyond human power to do more than conjecture as to the actual quantity and whereabouts of petroleum in the undrilled regions.

As development continues, our knowledge concerning the conditions which control oil accumulation increases and facts are brought to light which cannot be known without this development. New and improved methods are being devised for locating hidden structures that could not have been given full weight in former estimates of reserves. This discovery of new methods of oil finding and new underground conditions controlling accumulation is progressive, and is continuously adding to our conception of petroleum reserves. When it is considered that the same kind of development will add to our knowledge in the future, and that we are in the early stages of the use of scientific and mechanical appliances for structure finding, it must be concluded that estimates of reserves in barrels, based upon our present knowledge of conditions, are likely to perpetuate the same inaccuracies that have characterized past efforts.

Because of these uncertainties, we have made no effort to estimate the barrels of oil which may be recovered from fields yet to be discovered; but have confined our barrel estimates to those reserves sufficiently known to permit our gauging them within a limit of error of not more than 25 or 30%; that is to say the oil to come from now producing wells, from proven but undrilled properties and the oil left in the ground after flowing and pumping have failed. Since we believe these barrels of oil represent only a small part of our total potential reserves, we have coupled with this estimate a view of the future possibilities as seen by executives, operators and geologists in the industry. We believe this method of treatment is more capable of bringing about sound conclusions as to the potential petroleum supply of this nation than any barrel estimate that can be made.

Reserves in Known Fields.—Table A, pages 58-59, shows in detail for individual states, and for the United States as a whole, the data as to proven and producing acreage, areas possible for the discovery of new pools, number of producing wells, past production and estimated future production from producing and proven acreage by pumping and flowing, and the estimated quantity of oil left in the ground after these methods fail.

A total of 658,059 wells have been drilled in the United States. Of these 133,453 were failures and 228,447 were either gas wells or have been abandoned. There remain 296,147 producing oil wells in the United States, and the area these wells either are draining to-day or prove beyond any reasonable doubt for future production, will produce a quantity estimated at five billion, three hundred twenty-one million, four hundred twenty-seven thousand (5,321,427,000) barrels of oil. This figure is the aggregate future production of all the producing fields in the United States by present flowing and pumping methods, estimated conservatively by men from each individual field. This oil is yet to be recovered by flowing and pumping methods. The production of this petroleum, because of the nature of oil recovery, will be spread over a period of fifteen to fifty years.

The production of casing-head gasoline from oil wells has grown from almost nothing in 1911 to over 900,000,000 gallons in 1924. In comparison with the production of oil there has been a gradual increase in the amount of gasoline produced from casing-head gas from .2 of a gallon to each barrel of oil produced in 1915, to approximately 1.4 gallons for each barrel of oil produced in 1924. This increase in comparative ratio has been gradual as the industry has widened its scope of operations and improved its methods. The present upward trend indicates that more than 1.4 gallons of casing-head gasoline will be produced to each barrel of oil recovered in the future from all wells in the United States, including those yet to be drilled. Since a large part of our production, upon which this ratio is calcu-

lated, is in the flush stage, and comparatively much leaner in natural gasoline content than the gas from wells a few months or a few years old, we must expect wells now producing, from which we estimate a future production of three billion, two hundred ten million (3,210,000,000) barrels, to yield, as they grow older, considerably in excess of the present ratio of 1.4 gallons of natural gasoline per barrel of oil; that is to say, considerably more than 90,000,000 barrels of casing-head gasoline. Wells yet to be drilled on already proven acreage should yield an additional 60,000,000 barrels, making a total proven reserve in excess of 150,000,000 barrels of casing-head gasoline. This, of course, makes no allowance for casing-head gasoline from fields yet to be discovered.

Wells now producing will yield an estimated future production of three billion, two hundred ten million (3,210,000,000) barrels of oil. On the basis of 1.4 gallons of gasoline per barrel of oil, they should produce 90,000,000 barrels of gasoline in the future. However, since these wells are now largely in the flush stage and since the gasoline content should increase as they grow older, they probably will yield considerably more than the estimated 90,000,000 barrels of gasoline.

There has already been produced seven billion, eight hundred seventy million, nine hundred forty-eight thousand, four hundred sixty-six (7,870,948,466) barrels of oil from all wells in the United States, which, added to the estimated quantity still obtainable by pumping and flowing gives a total recovery by this method of thirteen billion, one hundred ninety-two million, three hundred seventy-five thousand, four hundred sixty-six (13,192,375,466) barrels from the present known fields.

Oil in Ground after Flowing and Pumping Cease.—It is the general opinion of executives, engineers, and geologists throughout the country, that there will still remain in the ground after all pumping and flowing have ceased more than twenty-six billion (26,000,000,000) barrels of additional

oil. That is to say, there will remain in the ground after present flowing and pumping methods cease about two barrels of oil for each barrel previously produced. That this figure for oil remaining in the ground is conservative may be inferred by comparison with a recent estimate by David White of the United States Geological Survey. White states that two billion, five hundred million (2,500,000,000), barrels of oil remain in the Bradford sand, which covers more than 100,000 acres in Pennsylvania and New York. The Bradford sand was originally exploited in 1869, and reached its peak production of 63,000 barrels daily in 1881. It had declined to a production of a little more than 5,000 barrels per day, in 1906, and has made a total production of about 60,000,000 barrels to date. This sand then, which is practically exhausted for flowing and pumping production, is estimated by White still to retain nearly ten times as much oil as it produced in its flowing and pumping life.

With improved methods of recovery such as mining, flooding, restoration of pressure and other scientific methods yet to be devised, we believe a *large proportion of this oil can be recovered* from the present producing fields. The production of this oil, because of the nature of its occurrence, must necessarily be spread over a long period of years.

Recovery Methods.—Due to the fact that recovery of this type of oil has been so little attempted in this country, it is impossible to determine just what per cent of the total should be classified as available supply. In Pennsylvania and New York application of flooding processes is recovering as much oil as was had by flowing and pumping. In Ohio, Oklahoma, and Kansas restoration of pressure by induction of air or gas has met with results which indicate equal success. Experiments are being made with mining processes, and it is probable they will develop to such an extent that the last stage in oil recovery, in many of our fields, will be that of bringing the partially saturated sand to the surface and washing or retorting for the last barrel of oil it contains.

There are, then, by way of reserves definitely in sight five billion, three hundred million (5,300,000,000) barrels of oil, conservatively estimated, to come from areas already producing or proven, plus a future supply of casing-head gasoline equal to the straight-run-gasoline yield of an additional one billion (1,000,000,000) barrels of crude oil of fair grade. After this oil has been produced we have still left in the ground an estimated quantity of twenty-six billion (26,000,000,000) barrels of oil, or more than three times as much as our total past production. The total quantity of oil definitely known, therefore, is more than thirty-two billion (32,000,000,000) barrels. And nowhere in these figures has there been allowed for a single barrel of oil to come from oil fields that may be discovered in the future.

It is the opinion of the industry, that all of this oil is actually proven, and in addition to this known quantity it is likewise believed that numerous producing fields will be discovered in the extensive unproven territory which is similar in general geologic character to those areas now producing. It must be kept in mind, however, that most of this oil can be captured only at costs greater than those which have prevailed in the past. It is becoming more expensive to find new fields each year. Lease bonuses are gradually increasing; scientific investigation is becoming more involved and more expensive, and drilling to greater depths is necessary. All these, together with the additional costs of improved methods of recovery make it inevitable that the next eight billion (8,000,000,000) barrels of oil produced in this country will cost more than the last. There is in the ground a large quantity of petroleum; whether we choose to recover it and utilize its production or to develop substitutes for these products, is a question of dollars and cents rather than the existence of the necessary commodity.

New Oil Fields.—The total area in the United States in which the discovery of new oil fields is possible is one billion, one hundred five million, four hundred fifty-four

thousand, four hundred fifty-nine (1,105,454,459) acres, and the total area unfavorable for oil is 827,790,752 acres as shown in the following tabulation:

Districts	Area in which New Oil Fields May be Found. Acres.	Area Unfavor- able for Oil. Acres.
Eastern States.....	179,893,860	174,097,100
Kentucky, Tennessee and Southeastern States.....	148,925,036	63,078,112
Mid-Continent and North Central States...	248,088,130	86,722,560
Texas, Louisiana, Arkansas and Mississippi.	241,502,837	30,081,980
Rocky Mountain and Pacific Coast States..	287,044,596	473,811,000
Total.....	1,105,454,459	827,790,752

The area designated as unfavorable for the discovery of new fields includes exposures of igneous or metamorphic rocks and areas where, in the light of our accumulated experience, structural or stratigraphic conditions are known to be unfavorable for oil production. Some small favorable areas have been included with surrounding larger unfavorable areas, and some areas of very old sediments, even though not metamorphosed, have also been classified as unfavorable.

About 57% of the total area of the United States is such that new oil fields may be discovered in it, whereas 43% as described above is unfavorable for the occurrence of petroleum.

The rocks underlying the entire area in which the discovery of new oil fields is possible, are of the same general character as those which yield the production from our proven fields. Over a considerable portion of it, other conditions which characterize the areas now producing in our present fields are known to exist. Throughout this part of it, and distributed over much of the possible area, are the oil fields which we have already discovered.

It would be a mistake, of course, to assume that all of the area designated as favorable for the discovery of new fields is to produce oil, and such an assumption is in nowise to be inferred from this discussion. The known requisites for oil fields are such that even in the most favorable territory only a very small proportion of the entire area yields production. Adequate source beds must be brought into close juxtaposition with appropriate reservoir rocks, and the combination of source and reservoir must acquire a special structural relationship before accumulation of petroleum can be effected. Only a very small per cent of the total area will become producing territory, or contribute to our supply of crude oil. But at intervals, widely spaced, perhaps, over the entire possible area, new oil fields may be found.

New Production from New Sands Likely.—There is good evidence that in every one of the producing areas in the United States oil will be obtained in sands other than those now producing. Even in the Eastern fields, including the Appalachian District, where exploration has been active for more than a half century, it is reasonable to hope that new production will develop from some of the tests that are being drilled to deeper sands. In the Mid-Continent area, in Texas and the Gulf Coast, in the Rocky Mountain region, and in California production is to be expected in many fields from sands other than those now yielding our oil.

Improve drilling methods will be perfected which will permit of exploration to depths much greater than those now attainable, and that over large parts of the area in which the discovery of new oil fields is possible, as well as in many of our proven fields, deeper drilling may open new reserves and very greatly increase our supplies of petroleum.

Improvements in geologic technique and more intensive application of scientific methods in the location of undiscovered oil deposits will become of increasing importance in

the future as improvements in present methods and discovery of new methods and principles are made. Judging by the progress that has taken place in the past five years and the success that has already attended the use of scientific instruments in attempts to locate structures favorable for oil accumulation, there is reason to believe that the new methods will enable us to determine in advance of drilling the position of many favorable areas, which otherwise would be discovered only by haphazard drilling. The application of these methods will assist materially in the exploration of the large area in which the discovery of new oil fields is possible and will tend to offset the increasing difficulty of maintaining our oil supply. They should be considered as one method of defense against vanishing production.

Much oil has been found in the past in areas where there is no evidence of favorable structure at the surface. A large additional number of such occurrences must await the same chance discovery of haphazard drilling, in spite of all anticipated improvements in the technique of finding oil. It will require many years to complete the list of discoveries of this class, however intensely the search may be prosecuted over the area possible for the discovery of new oil fields.

The discovery of new oil fields is, by its very nature, a pioneering enterprise. The history of the oil industry is replete with instances in which new areas have been brought into production where conditions favorable for petroleum accumulation, as understood at the time, were believed to be non-existent. Important discoveries of such fields have been made in the last few years in areas which on the basis of the information available at the time were placed in the same class as the area here designated as possible for the discovery of new oil fields. There is every reason to believe that future exploration will repeat the accomplishment of the past, with the result that many new producing districts will be discovered in the extensive area possible for the discovery of new oil fields.

In other words, for several years the discovery of new fields in the United States has developed at an accelerating rate. Even though acceleration has reached a maximum, which is unlikely, the rate would still not be expected to fall immediately to zero; at worst, it would remain constant for a considerable period after attaining a maximum value before it commenced a gradual decline which might reasonably be expected to persist over a period of years.

Every new field developed adds to the back-log of our settled and semi-settled production so that each year the number of new fields necessary to maintain our output is less. Recently our discoveries have been at a rate greater than that required by our consumption of petroleum, with the result that the industry has been constantly in suspense at the prospect of a further burden of over-production from threatened new fields.

Future Oil Supply.—An analysis of the considerations set forth in the preceding paragraph convinces us that we can certainly expect a large supply of petroleum over many years. Our considerable reserve from wells and fields already producing, plus the oil to come from known deeper sands, not now producing in these fields, plus the oil from new fields and new districts in the large area yet to be thoroughly explored, plus all the oil left in the ground after flowing and pumping cease in the fields already exploited in the present proven fields, and in the fields yet to be discovered, impress us as an imposing quantity in comparison with our past production.

RECOVERY METHODS AND PRACTICES

Exploitation Policy.—The sub-committee's work leads it to conclude that our present competitive drilling and producing policies result in a maximum recovery of oil by flowing and pumping methods. Competitive drilling compels the rapid completion of more wells than are compatible with maximum operating profit, but it is the general opinion of the industry that every well drilled in a field adds to the

number of barrels of oil recovered by flowing and pumping from that field. If all wells are completed at approximately the same time, maximum recovery is obtained. The first wells in on a lease are the best producers as a rule, and leases drilled up slowly or after other leases are fully drilled, never get their full share of the oil.

Waste of Oil and Gas.—The present methods of producing oil are the outgrowth of many years of actual producing experience. Progress is being made continually by study and experiment both by the old-time producer schooled in experience and the well-trained technical engineer. The cheapest oil produced is that obtained by flowing, hence every effort is made to keep wells flowing naturally. Gas coming with the oil is used to the greatest efficiency compatible with its market value at the well. Seldom is an appreciable amount of gas wasted by good operators, except in rare and virtually unavoidable instances, or where it costs more to save the gas than it is worth. Present practice loses to fuel uses a small proportion of the gas produced with oil, but even this gas does useful work as the expanding agency which causes wells to flow. Possibly gas produced with oil could be made a little more efficient by improved physical control, but this possibility is not established as yet.

Present production methods are as efficient as is warranted by the value of the product handled. The waste in the industry is virtually negligible and the oil left in the ground becomes a reserve for the future.

Edge and Bottom Waters.—Edge and bottom water undoubtedly damage individual properties affected. However, the consensus of opinion on this problem, as shown by the answers to the questionnaire sent by the Committee on Supply, is that bottom water is either shut off effectively, or in some instances used to advantage in producing oil; that edge water does not injure as much as it aids oil production. Naturally, as the oil is exhausted from a sand where water backs up the oil, the oil is replaced by water as the oil is produced.

Back Pressures on Producing Wells.—It is generally conceded that back pressure prevents the coning up of water, where the latter is found at the base of the oil measures in some fields. It is also of value in the prevention of cutting out of screen and oil well fittings in fields where the sands are close and gas pressures high. There is some difference of opinion relative to the value of back pressure for increasing the ultimate recovery of oil. A number of experiments and observations on the use of back pressure indicate that more oil will be recovered by flowing and that the flowing period will last longer, if back pressures or other means are used for conserving in the sands, the gas in excess of that necessary to flow the well. This does not mean necessarily that the ultimate recovery will be greater. It does clearly indicate that a large proportion of the oil may be recovered at a less cost. Of course, if there is no excess of gas above that necessary to flow the well, back pressures are out of the question.

Research on Production Methods.—It is believed that for every barrel of oil produced in this country two or more barrels remain in the ground. A considerable part of this oil can be brought to the surface at a reasonable cost by methods known to-day, yet, a large part of it is probably not available as a supply through the use of processes now employed. It may never be necessary to attempt to produce this remaining oil. However, since it exists, and is an assurance to us of an era of production as great as or greater than that through which we will go by flowing and pumping methods, it should be studied. This study cannot be carried on at profit at this time. If we wait until this oil is needed prices will soar beyond all reason before methods are evolved to produce it. In order to eliminate the possibility of this condition arising experiments should be started now and carried on, not with the idea of profit, but for the assurance of being prepared should an emergency requiring such oil arise.

There are a number of problems relating to the technical

phase of oil production which we believe possible of solution, but on which so little scientific and experimental work has been done that they remain a fruitful field for the prosecution of research. To date oil companies have not been able to carry on as much of this type of work as is desirable, so that those experiments which have been made have to a large extent been performed by governmental agencies. Due to the lack of funds, however, these agencies have not been able to prosecute this work with broad enough scope to keep pace with the development of the industry. We find oil companies are showing an increased tendency to enter this field of endeavor, and we believe that within a few years practically all companies will have their own research departments. When this develops there will be an enormous duplication of effort in solving those problems which embrace basic scientific principles that are purely mathematical, physical, and chemical. It is, therefore, highly desirable that some form of cooperation be immediately established among oil companies to make a study of these basic principles, in their application to the practical problems of the industry.

TABLE A.—DIVISION OF CLASSIFICATION OF PETROLEUM ACREAGE,

Division by States	Total Area	Number of Producing Wells	Present Production Per Day	Total Production to Date	Pro- ducing Area	Proved Unde- veloped Area
	(Acres)		(Barrels)	(Barrels)	(Acres)	(Acres)
Minnesota.....	51,749,120					
North Dakota.....	44,917,120					
South Dakota.....	49,195,520					
Nebraska.....	49,157,120					
Missouri.....	43,985,280					
Kansas.....	52,335,360	18,318	84,200	345,000,000	139,300	175,700
Oklahoma.....	44,424,960	56,677	495,857	1,640,000,000	374,790	264,000
Total.....	335,764,480	74,995	580,057	1,985,000,000	514,090	439,700
Kentucky.....	25,982,720	12,737	22,422	69,673,000	253,344	84,448
Tennessee.....	26,894,080	32	500	86,000	320	500
Alabama.....	33,278,720					
North Carolina.....	31,193,600					
South Carolina.....	19,516,800					
Georgia.....	37,929,600					
Florida.....	37,546,240					
Total.....	212,341,760	12,769	22,922	69,759,000	253,664	84,948
Arizona.....	72,931,840					
Colorado.....	66,526,720	71	968	11,410,000	2,504	3,241
Idaho.....	53,688,320					
New Mexico.....	78,485,760	7	500	91,218	640	13,960
Montana.....	94,078,080	204	8,223	9,631,000	2,390	490
Utah.....	54,393,600	5	50			
Wyoming.....	62,664,960	2,480	106,650	198,470,000	35,880	7,363
Nevada.....	70,841,600					
Washington.....	44,241,280					
Oregon.....	61,887,360					
California.....	101,310,080	11,380	602,000	2,124,066,000	62,229	63,303
Total.....	761,049,600	14,147	718,391	2,343,668,218	105,647	88,357
Arkansas.....	33,616,000	3,024	102,900	117,028,923	35,940	4,230
Louisiana.....	34,645,000	3,527	58,025	316,589,212	50,215	5,670
Mississippi.....	29,671,000					
Texas.....	174,334,000	18,506	411,864	885,574,113	162,128	423,000
Total.....	272,266,000	25,057	572,789	1,319,192,248	248,283	432,900
New York.....	31,490,560	14,400	4,060	59,808,000	60,000	2,000
Pennsylvania.....	28,880,640	76,664	20,628	780,318,000	380,000	11,000
West Virginia.....	15,468,800	19,847	16,230	338,179,000	150,000	10,000
Ohio.....	26,265,600	39,050	18,621	506,529,000	275,000	20,000
Indiana.....	23,266,500	2,505	2,564	112,246,000	30,000	3,000
Illinois.....	36,265,600	16,731	22,030	357,157,000	124,000	12,000
Maine.....	21,145,600					
New Hampshire.....	5,978,240					
Vermont.....	6,120,900					
Massachusetts.....	5,290,240					
Rhode Island.....	798,720					
Connecticut.....	3,177,600					
New Jersey.....	5,263,360					
Delaware.....	1,516,800					
Maryland.....	7,889,280					
District of Columbia.....	44,800					
Virginia.....	27,281,280					
Michigan.....	37,107,200					
Wisconsin.....	35,882,240					
Iowa.....	35,934,000					
Total.....	355,067,960	169,179	84,134	2,153,329,000	1,019,000	58,000
Grand total.....	1,936,489,800	296,147	1,978,293	7,870,948,466	2,140,684	1,103,905

PRODUCTION AND RESERVES FOR THE UNITED STATES

Areas Within Which Oil Fields may be Found	Unfavorable Areas	Reserve of Producing Wells (Common Methods of Flowing and Pumping)	Reserve of Proved Undeveloped Acres (Common Methods of Flowing and Pumping) (Barrels)		Reserves of Producing and Proved Acres (Common Methods of Flowing and Pumping)	Estimated Amount of Oil Left in Ground Under Producing and Proven Areas After Flowing and Pumping Cease
			Barrels Recoverable Under Present Conditions of Industry	Barrels Recoverable at Some Price		
(Acres)	(Acres)	(Barrels)			(Barrels)	
.....	51,749,120					
41,613,440	3,303,680					
44,182,400	5,013,120					
49,157,120						
19,554,560	24,430,720					
52,020,360		120,380,000	79,610,000	114,511,000	314,501,000	1,539,000,000
41,560,250	2,225,920	572,163,000	123,800,000	343,130,000	1,039,393,000	6,251,000,000
248,088,130	86,722,560	692,543,000	203,410,000	457,641,000	1,353,394,000	7,790,000,000
24,648,064	996,864	78,974,000			78,374,000	446,000,000
25,382,597	1,510,663					
21,471,655	11,807,065					
8,458,240	22,735,360					
10,311,040	9,205,760					
21,107,200	16,822,400					
37,546,240						
148,925,036	63,078,112	78,974,000			78,974,000	446,000,000
		2,225,000	46,237,000		48,462,000	179,616,000
237,333,408	316,209,000	1,450,000	11,450,000		12,900,000	38,977,000
		5,478,000	4,422,000		9,900,000	58,593,000
					500,000	1,500,000
		137,671,000	157,879,000		295,550,000	1,482,060,000
8,241,280	36,000,000					
10,755,360	51,132,000					
30,714,548	70,470,000	1,207,048,000	932,939,000		2,139,987,000	12,792,159,000
287,044,596	473,811,000	1,353,872,000	1,152,927,000		2,507,299,000	14,552,905,000
25,575,830	8,000,000	101,000,000	21,150,000		122,150,000	239,179,000
34,589,115		105,520,000	28,350,000		133,870,000	450,459,000
29,671,000						
151,666,892	22,081,980	520,540,000		211,500,000	732,040,000	1,617,614,000
241,502,837	30,081,980	727,060,000	49,500,000	211,500,000	988,060,000	2,307,252,000
10,893,560	20,535,000	15,000,000	1,000,000		16,000,000	100,000,000
10,706,640	17,783,000	80,000,000	6,000,000		86,000,000	520,000,000
7,708,800	7,600,000	43,000,000	5,000,000		48,000,000	193,000,000
23,328,600	2,642,000	110,000,000	10,000,000		120,000,000	209,000,000
21,463,500	1,770,000	10,000,000	1,500,000		11,500,000	41,000,000
32,289,600	3,840,000	100,000,000	12,000,000		112,000,000	236,000,000
	21,145,600					
	5,978,240					
	6,120,900					
	5,290,240					
	798,720					
	3,177,600					
	4,028,000					
1,235,360	516,000					
1,000,800	5,450,000					
2,439,280	44,800					
	25,060,000					
2,221,280	8,486,000					
28,621,200	32,587,000					
3,295,240	1,244,000					
34,690,000						
179,893,860	174,097,100	358,000,000	35,500,000		393,500,000	1,298,000,000
1,105,454,459	827,790,752	3,210,449,000	1,441,337,000	669,141,000	5,321,427,000	26,394,157,000

SUPPORTING DATA

PETROLEUM RESERVES

Reserves in Known Fields.—The production figures and maps on which are based estimates of the amount of future oil to come from known producing and proven areas, are contained in the reports of the various technical sub-committees. These figures are summarized in the first pages of this report. The estimates are based on decline curve data for individual fields and in each case are made by men familiar with that particular field. Every field in the United States has been studied in this connection and the estimated future production as set up in Table A on pages 58-59 is believed to be conservative. The quantity of oil remaining in the ground is also conservatively estimated.

New Oil Fields.—The area in which new oil fields may be discovered, has already been defined and described as to general character. It is useless to attempt here to describe in detail the geology of this immense area. The publications of the United States Geological Survey and the various State Surveys include many volumes discussing in detail the petroleum possibilities of the area in which new oil fields may be expected. This area is of the same general character as the area which has produced and is producing our crude oil supply,—and it has been tested much less thoroughly than has usually been necessary in the past for the development of new oil fields. With this great area to be explored and with increased efficiency of exploration methods, additional oil fields will certainly be discovered.

There are several factors important to the possibilities of new discoveries. These factors are, first, the presence in producing and proven areas of sands other than those now producing, either shallower or deeper in the geologic section; second, improved methods for aiding in the location of new oil fields; and third, possibilities for commercial

accumulation not controlled by favorable geologic structure.

In every one of the producing regions in the United States oil will very probably be obtained in sands other than those now producing. Even in the Eastern fields including the Appalachian District, where exploration has been active for more than a half century, it is reasonable to hope that new production will develop from some of the tests that are being drilled to deeper sands. In the Mid-Continent area, in Texas and the Gulf Coast, in the Rocky Mountain region, and in California; production is to be expected in many fields in each of these sub-divisions of the nation's petroleum reserves from sands other than those now yielding our oil. In a number of cases the deeper sands from which production is expected have already made oil commercially elsewhere. The shallow sands not now being exploited have generally been drilled through and cased off in order to recover more attractive production in the reservoirs now producing. With better market conditions, or with the depletion of the sands now producing, these shallow sands will be exploited.

In the producing fields in the eastern United States, but little new oil is expected from shallow sands, although new fields will continue to be found in these sands in outlying areas. But deeper sands merit the tests that have been and are being drilled by the companies operating in this territory. The important deep sand possibilities include the Corniferous Limestone (producing in Kentucky), Oriskany Sand (producing in New York), Medina White Sandstone, Clinton Sand of southern Ohio, and the Trenton Limestone (producing in Indiana, New York, and Kentucky).

In Ohio, Indiana and Illinois, there are still some possibilities for new, deeper pay in the Trenton Limestone.

In the Mid-Continent fields oil has repeatedly been found in lower sands after common agreement held that all producing horizons had been tested. It has become clear, that only after the drill has penetrated igneous or metamorphic basement rocks, are the possibilities exhausted.

It is estimated that only 40% of the producing fields in this area have been tested in the Wilcox Sand which is a most prolific reservoir rock in a number of pools, and in only 5% of the producing fields has the still lower Turkey Mountain (Silicious Limestone of Ordovician age) been tested. There are also a number of known shallow sands, not now producing, which will eventually be brought into production.

Deeper Sand Possibilities.—The deeper sand possibilities of Texas, Louisiana, Arkansas and Gulf Coast fields, where oil is being obtained in beds of extremely recent geologic age, as well as from beds of extremely great age, are exceedingly good. Beneath the lowest producing horizons in parts of the Mid-Continent and the Eastern fields, igneous or closely folded rocks, too dense to be promising for oil production, are usually encountered, but beneath the Cretaceous and Tertiary fields of Texas, Louisiana, and Arkansas, known sands are to be expected down to the greatest depths which we can hope to attain with the drill, and these sands, even though under heavy cover, are probably neither too much metamorphosed nor too severely folded to permit of petroleum accumulations in them. The only limit in this territory appears to be the maximum depth to which we can drill in the future.

Of Texas, it can truthfully be said that no producing field in the State has exhausted the possibilities of deeper sands. As in the case of Oklahoma, so in Texas, there is oil in the Ordovician rocks, and from this era forward through geologic time, producing beds are found in the major geologic units represented in the State, including Mississippian, Lower Pennsylvania, Permian, Lower Cretaceous, Upper Cretaceous, Eocene, Oligocene, Miocene and Pliocene. There is abundant basis for the belief that additional oil will be developed from lower sands in the fields now producing from all of these rock-series. The same statement as to the promise for lower producing horizons may be made for every field in Louisiana and Arkansas. There are known producing sands present and not adequately tested below the

present production in each case. The details of these possibilities are discussed in the Group report covering Texas, Louisiana, Arkansas and Mississippi.

Like Oklahoma, again Texas, Louisiana and Arkansas possess known shallow sands which have been ignored in some fields and are at present cased off to permit the exploitation of deeper sands first.

Two Producing Beds in Rockies.—The producing beds in the Rocky Mountain States are of two main classes; one is of Cretaceous age and yields light gravity, green oil; the other is of pre-Cretaceous age and yields mainly black oil.

The bulk of the production has come from the Cretaceous sands, which are really separable into the Frontier formation with its well-known Wall Creek sands, and the Dakota Group with its variously known sands—Muddy, Dakota, Lakota, Cloverly, Kootenai and others. The main production at Salt Creek, Grass Creek, and Elk Basin has come from the Frontier sands, while at Cat Creek, Lost Soldier, and Rock River, it has come from the Dakota group. The black oil in Wyoming now chiefly comes from the Tensleep sand (Pennsylvanian), but some also comes from the Sundance (Jurassic) Chugwater (Triassic), and Embar (Permian) formations.

The Shelby, or Kevin-Sunburst field, as it is often called, is abnormal in that it produces from beds at the unconformity between the Mississippian and immediately overlying Jurassic. Oil comes from both the Ellis Sand (Jurassic) and the Madison Limestone. Deep tests to the Devonian and perhaps to the Cambrian have been failures.

The Cat Creek Field in Montana has not been tested much below the Kootenai. It may produce oil in lower sands.

Good production has been found in the Tensleep Sands at Grass Creek, Wyoming, which is now an important black oil field. This lends color to the belief that in other oil fields, few of which have been tested through the Tensleep,

and in important gas fields like Oregon Basin, Buffalo Basin, Hidden Dome, and Bryon, this horizon, or other sands below the Cretaceous may be productive.

Recent development at Salt Creek has proven that the Lakota sand, below the Frontier Sands from which the present production comes, will be an important factor in the future production of this field. Its area has not been fully determined but is approximately that of the first Wall Creek. The sand is about 50 feet thick. Salt Creek may also yield from below the Lakota. No tests have penetrated lower, but the sands of the productive Jurassic and Pennsylvanian formations underlie the field.

Lost Soldier has never been drilled to the Tensleep Sand.

The producing sand at Fort Collins, one of the important new fields in Colorado, is underlain by two more sands of the Dakota group, which may be productive when tested.

Future Promise in California.—In California deep-sand exploration holds great promise for the future. Some of the details are discussed in the following paragraphs:

In the Coalinga field there is evidence that deeper sands, other than those now producing, might produce. Tests made a number of years ago on the Coalinga East Side Anticline proved that such deeper oil does exist. This oil was produced by one well on the Standard Oil Company's property in Section 28, which made about 80 barrels per day of oil of a mixed base, containing a considerable portion of paraffine.

In the Midway-Sunset field most of the production so far obtained has come from a series of sands, sandy shales, and clays, which rests with considerable unconformity upon a very thick series of Miocene shales. In some localities wells carried below this contact into Miocene shales have penetrated sandy members which have proved productive. The successful development of the Hovey Hills area is a concrete example of the possible productivity of this lower horizon. Wells drilled into this have produced at a rate of over 200 barrels per day. In the eastern portion of the

Midway-Sunset District, especially on the Buena Vista and Elk Hills Structures, the brown shale has not been tested by drilling. It still remains to be proven whether or not there are under these structures deeper oil measures such as have been found in the Hovey Hills.

In Southern California deeper sands are to be expected in the fields now producing. Comparatively recent development in the West Coyote field has proven the existence of a rich oil-bearing horizon or zone, which has been called "99-Zone," at approximately a depth of 4,000 feet. Two wells have been drilled into the 99-Zone; spaced approximately 2,000 feet apart. The limits of this zone have not been definitely established, but there is no doubt of its high productivity. The ultimate recovery from these deeper sands will run into tens of millions of barrels.

A deeper zone of probably limited extent has been proven by one well on the upper part of the Montebello or Baldwin Hills structure.

Even within the inhabited area of the city of Los Angeles there is evidence of deeper sands below the zone from which the historic wells of this community derived their early and widely advertised production. It is now impossible to drill a test for the purpose of exploration because of a City Ordinance prohibiting drilling. Should it become essential for national defense, however, this field would, no doubt, be tested for deeper sands.

In the first year of development at Rosecrans four producing "zones" were put into production. It is possible that still deeper zones will be found, as oil sands from depths below 6,000 feet have been recovered by coring.

The present producing zone at Dominguez is underlain by a second zone proven by cores, but as yet no attempt has been made to obtain production. The developments of Santa Fe and Long Beach fields, indicate the possibility that one or even more productive zones may be found at a still deeper horizon at Dominguez.

The East Coyote field offers some possibilities for a

deeper zone production but its extent cannot yet be estimated. One small well has been successfully completed in this lower zone.

Production is obtained at Brea-Olinda from a fault-contact structure, rather than a closed fold. The sustained production and large undrilled reserves make this field of importance. Geologic correlations suggest possible deeper productive horizons which, if proven, will add large reserves.

Improved Prospecting Methods.—The foregoing paragraphs cover briefly the situation as to known sands not now producing in the present oil fields, and the promise of these sands in connection with new oil fields. An equally important factor in making new discoveries of oil fields probable is the improvement in methods for prospecting and exploring for oil.

In the early days of the oil business, the personnel of the industry was drawn from non-technical ranks and only the past few years has serious thought been given to the problem of locating hidden underground structures. But in recent years there has been a gradual acquisition of scientifically trained men in the industry and many such men are now at work on this problem.

Coring methods, especially in areas which are covered to a depth of a few hundred feet by flat lying formations, will be of particular value in the working out of favorable structure. In the Rocky Mountain states, in California, the Mid-Continent, and in Texas there are large areas where the surface is covered by flat lying recent deposits, or where the surface formations are not conformable with the sub-surface. In some of these areas, coring to a depth of a few hundred feet through the upper formations will permit of a determination of the dip and structure of the sub-surface beds.

In the Mid-Continent oil fields, core drilling (either by the diamond drill or ordinary rotary method) has been employed to advantage. By this means the Marland Oil

Company found the prolific northwest extension of the famous Tonkawa field of Oklahoma. The core drill, to a large extent, outlined this field and facilitated its development. Core drilling must also be given the credit for the discovery of the Hubbard, Braman and Thomas fields of Oklahoma, while in Kansas the finding of the Graham field and the Padgett gas field were also the result of the core drill. A number of other underground structures have been located, and it is quite likely that some of them will eventually be productive. In California the discovery of the Rosecrans field was materially aided by the core drill.

Improvements have been made within the past year in the taking of cores from wells. To date no satisfactory device has been worked out which would enable the obtaining of an oriented core. The use of cores for determining the amount of dip even without an orientation is of value. If oriented cores can be obtained, their value will be increased.

Paleontologic examination of well cuttings will open up new sources of oil. The optical examination of cores to determine the general character of the column represented is further strengthened by a microscopic examination of the fossilized remains of foraminifera and other minute organisms both from strata exposed at the surface, and from core samples. These studies may also lead to correlation by microscopic examinations of the so-called "heavy mineral group."

This branch of the science of oil finding is in its infancy, but already is making its influence felt in California, in the Mid-Continent and in the Gulf Coast States. Paleontological correlations by the Standard Oil Company of California led to the discovery of the prolific deep sands known as the "99-Zone," in the West Coyote Field of California. As additional information is secured, the scope of this work will be greatly enlarged and better results will be obtained.

Considerable research work has been done in correlating various underground waters, employing both chemical and

physical analyses for identification. While no new oil fields are known to have been found by this work, yet an intensive knowledge of the characteristics of the different water levels of a district can be of inestimable benefit in the search for new fields.

The oil industry itself is contributing no small aid in the finding of new pools of oil by keeping more accurate and more complete records of all wells drilled. Careful and painstaking records are invaluable, particularly in wildcat areas. The correct interpretation of such information led to the discovery of the Wortham field in Texas, and the Powell field in the same state was indicated before discovery, principally, by the records of a number of dry tests in the immediate vicinity.

Torsion Balance and Seismograph.—The most notable progress in the application of new methods, has been made in the past few years in the Gulf Coast area of Texas and Louisiana, where the salt dome type of structure governs oil accumulation. Geophysical methods have been applied with notable success, and it now appears that these methods will completely succeed the older methods of locating these structures.

The discovery of three domes, Nash, Orchard and Long Point in the Texas Gulf Coast region in 1924, by means of the torsion balance and the seismograph, is the first result of exploration by geophysical methods. Domes other than those mentioned have no doubt been found during the last few months of the year but tests have not been drilled to confirm the evidence of the instruments.

The Rycade Oil Corporation operated the first torsion balance on the Gulf Coast in October, 1922, and the Roxana Petroleum Corporation brought in one of these instruments and began work in December, 1922. The United States Coast and Geodetic Survey made some gravity observations at Damon Mound in 1923 with a pendulum apparatus. In March, 1924, the Marland Oil Company placed the first seismograph on the Gulf Coast and the Gulf Pro-

duction Company followed with one in May. In June, 1924, the Gulf Production Company began operations with a torsion balance. The Atlantic Oil Producing Company, the Texas Company, and others have experimented with several types of instruments involving various principles. During the next few years a great advance in geophysical methods may be expected especially if one of the newly discovered domes should be productive.

The Seismic Method.—A short description of the seismograph and the torsion balance, and of their apparent present success in the oil industry follows:

The seismic method is based upon the fact that mechanical waves set up in the earth by some shock, most suitably an explosion of dynamite, are transmitted at greatly different velocities in strata of different elasticity. In consequence, very sensitive, but portable seismographs, placed at some distance from an explosion, will register the earth-waves successively as they arrive, transmitted along various beds of different elasticity. The time required for their transmission, which can be accurately measured on a moving film, indicates the nature of such beds, whether clay, loose sand, sandstone, limestone, anhydrite, or rock salt, and also the approximate depth at which such strata lie, down to a depth of 6,000 feet or more.

So far, the seismic method has proven of practical value to the oil industry mainly as a means to locate hidden salt domes, which are not indicated at the surface. As is well known, oil usually occurs in a disconcertingly erratic manner in connection with salt domes. A detailed knowledge of the subsurface feature of a salt dome is a considerable help, and may avoid much disappointing drilling, but the final knowledge, whether and where oil is present in commercial quantities around the domes, can only be obtained through test wells. Seismic research is, therefore, merely a means of speeding up discovery of salt dome oil fields.

The seismic process is not the exclusive property of any single concern, although certain instruments are patented,

and certain individuals have considerable advantage over others, as a result of longer experience. The principles are as well understood as those of radio, and consequently can be applied by anyone who has sufficient ingenuity and knowledge of physics to devise suitable instruments and formulas.

Gravitational exploration is based upon the fact that minor deviations from the earth's gravitational attraction are caused by local differences in the specific gravity of masses underlying the surface. The attraction at one station will be greater if the average density of the upper horizons of the column of rocks underlying it is greater than at another station. These anomalies are extremely small, and it requires extraordinarily sensitive instruments to detect them reliably. The best instrument to date is Eotvos' torsion balance in its improved form.

This instrument can be used for the detection of salt domes, as the plug of rock salt is slightly lighter and its anhydrite cap is slightly heavier than the surrounding unconsolidated sands and clays of the Gulf Coastal plain. Also it may detect anticlines, especially if masses of comparatively denser rocks, like massive limestones or granite, are brought abnormally close to the surface along the axes of the folds.

The torsion balance has been used successfully in petroleum exploration on the Gulf Coast, and new salt domes have actually been discovered by it. There are other regions in the United States where the methods could be applied to detect buried upheavals, obscured at the surface by unconformably overlying younger formations.

The success of both the seismograph and torsion balance on the Gulf Coast has led to the belief that they will do as good work in other sections of the country where buried ranges and hills form the fundamental geological conditions for the accumulation of oil. It is not unlikely that these devices will be of material aid in locating new oil fields of the types of Mexia, Wortham, Currie, Powell and Luling,

where the controlling structural factor is a fault of considerable displacement. It may be that the effectiveness of the torsion balance and the seismograph will be greatly increased by a more intimate knowledge of the instruments and more work with them will lead to a better and more complete interpretation of their data, thus presenting a wider and more varied application of these devices.

While all the methods discussed have to do with the finding of underground structures rather than directly with oil, yet the relationship of subsurface structure and oil is so close that the possibilities for finding production are much enhanced if the structure is known. Nearly all oil fields, particularly the larger pools, are associated with underground structures and the value of determining the extent and location of those structures cannot be overestimated when searching for new oil supplies. With the thoughts of the various research departments turned towards mechanical means of locating underground structures, it is not beyond the realm of possibility that scientific apparatus will be perfected which will indicate the actual presence of oil. It may safely be predicted that many new fields will be opened up in the future by more precise geological methods in conjunction with the various scientific and mechanical devices already in use and others as yet unknown.

Another factor which enters into the prospect for additional discoveries of new oil fields arises from the fact that oil has often been found where there was no evidence of favorable conditions, structural or otherwise. This situation will continue to some degree in spite of our improved technique of exploration.

There are numerous instances in the fields of the United States where petroleum has been found to have accumulated elsewhere than on what is commonly considered to be favorable structure. In the fields of the Eastern States production is found on the tops and flanks of anticlines, and in synclines, indiscriminately; often also, the tops of the anti-

clines have been barren of oil. In Illinois structural control of accumulation is more effective and but little oil occurs except on anticlines. In Kentucky, the distribution of production is very erratic and is not closely controlled by structure.

Geologic Problems in Southwest.—The situation in the Mid-Continent area and in Texas is stated briefly in the following paragraphs:

The complex features of the geology of the Mid-Continent make it very difficult reliably to predict production on Mid-Continent structures. The irregularity of the sands, especially in the lower horizons above the main unconformity (there are several additional minor unconformities), makes the oil accumulation entirely dependent upon the presence, the thickness and grain of such sands. Sometimes certain trends of these sands may be deduced, indicating old beach lines, sand flats, or tidal spits. Usually, however, this is not the case, and only the drill can determine the direction of sand persistence. Likewise, only drilling can tell us, in many cases, whether in a producing oil field, the underlying Ordovician sands will be found preserved and favorable for production.

As our knowledge of the regional geology improves from the ever-increasing number of well logs, some of these uncertainties can be solved beforehand, through a better knowledge of the paleogeography of the region and resultant trends.

In Texas no production is known which is not controlled by local folding (or faulting) if we include structure caused by settling or sagging. Even in Archer County where accumulation is very erratic, it is controlled by noses, which can be followed by careful mapping of surface beds. There are numerous regions, however, where oil accumulation on the structure can only be located by drilling because it is dependent upon deposition, or limestone porosity, or other factors, which are often as important as the structure itself. The principal areas of this class are:

Cisco production in Archer County and surrounding; Strawn and Bend production on the Bend Arch; production in the Panhandle; Edwards production in the Luling region.

Furthermore there is another wide region where, although oil accumulation is clearly caused by structure, such structure cannot now be determined in advance of drilling, although it may be possible to do so in the future. The principal areas of this class are:

Permian production on the high plains of West Texas; Tertiary production in the southwest, between San Antonio and the Rio Grande.

In the Rocky Mountain states, but little drilling has been done except on favorable structure, perhaps for the reason that all discoveries to date have shown accumulations to be closely controlled by anticlinal structure. However this may be, the main production is almost wholly on the tops of well-formed and definitely closed anticlines with highly dipping beds. Rarely is the amount of closure less than 300 to 500 feet, and in most cases it exceeds 1,000 feet. In some of these anticlines there is production from accumulations along faults as in Elk Basin and Cat Creek.

There are, however, three cases of unusual occurrence where oil is produced without definitely favorable structure.

(1) At Shelby, Montana, on the enormous Sweetgrass Arch which covers many townships and has a minimum of more than 1,000 feet of arching, oil occurs along a major unconformity between the Madison Limestone of Mississippian Age and the Ellis formation of Jurassic Age. The oil is found in both the Ellis and the Madison. The field is very spotted, with some oil below the general water level. No positive method of locating the producing spots except drilling has been advanced so far.

(2) Osage, Wyoming, a small field, is more or less monoclinal on the west flank of the Black Hills. The oil occurs in the Newcastle sand of Cretaceous age, a few hundred feet above the Dakota sand which is water-bearing. The oil is probably trapped in lensing sand.

(3) At Artesia, New Mexico, the oil occurs with no definite surface indications of folding. The surficial covering precludes surface mapping. So far as well log data goes, only a very low monoclinal dip is shown. The oil is found in beds of Permian Age and may be associated with an unconformity.

In California, certain areas, particularly in the oil fields of the San Joaquin Valley, have a marked unconformity between the great mass of Miocene shales, which are the source of the oil, and the overlying Pliocene sands, sandy shales and clays in which are found the principal producing zones. Accumulation of oil has taken place near the contact of highly organic shale strata with the overlying sands, in some parts of the Midway-Sunset district which might be classed as "off-structure." There have been developed within the past two years two important extensions of producing territory of the above-described type: (1) on the northeast flank of the Buena Vista Hills, and (2) on the eastern flank of the 35 anticline. In these extensions wells of high productivity have been brought in. A condition of a similar nature has been known for many years along the eastern front of the Kern River field. In this locality the recovery of oil has been difficult due to the existence of bad water conditions. Sufficient wells, however, have been drilled to indicate that there may be large areas of this kind in California.

RECOVERY METHODS AND PRACTICES

Exploitation Policy.—Correct well spacing to obtain the maximum oil production from a given field may be considered either from the standpoint of economic return or theoretically to obtain the maximum amount of oil. In the latter case, under present methods of production, the percentage of oil left in the sands could not be reduced by drilling fewer wells than we now drill in a field. In some fields where there has been very close spacing, such as

one well to an acre or a little more, there has undoubtedly been a financial loss. In probably the majority of cases the quantity of oil recoverable increases as the distance between wells decreases up to a critical distance. After this is reached the recovery increase is not materially augmented by still closer spacing. A few investigators claim there would be as much oil obtained from a wider spacing of wells, but the big majority, including the technologists of the U. S. Bureau of Mines, believe that, considering production alone, more oil will be obtained the greater the number of wells.

An infinite number of wells drilled and produced in accordance with the latest methods would produce the maximum amount of oil. A lesser number of wells correctly located, finished and produced would give a somewhat smaller ultimate recovery and a much better economic return. The question to be determined in each field is: What is the maximum number of wells necessary to give the best economic result? This spacing of wells will vary with each particular field and be dependent on many conditions such as gas pressure, size and character of voids, viscosity and gravity of oil, thickness of the producing horizon, depth to the oil, drilling program and value of the oil. This spacing must vary from one well to ten acres or more, to one well to three or even less acres. As the factors which control well production cannot be determined with any degree of accuracy in advance of the drill, but can only be determined as the development of a field progresses, it is impossible to plan the most desirable well spacing until after a number of wells have been drilled.

Effect of Spacing at Santa Fe Springs.—A comparison of ultimate productions from two tracts in the Santa Fe Springs field in Southern California illustrates the effects of spacing. Tract "A" comprises 43.5 acres and has 8 wells producing from the Meyer Zone. Tract "B" comprises 27.5 acres in the closely drilled townsite area and has 42 wells producing from the Meyer Zone. Tract "A" was

chosen as a fair example of a tract with average spacing. It probably will produce ultimately more oil than most other similar tracts. Tract "A" is 800 feet distant from Tract "B" and separated from it by an area which is almost completely drilled with liberal spacing. It does not seem probable that Tract "B" has drained oil in appreciable amounts from Tract "A." However, it seems almost certain that Tract "B" has drained substantial quantities of oil from adjoining properties. The following tabulation shows the estimated ultimate recoveries from these tracts:

	Area, Acres	Number of Pro- ducing Wells	Spacing, Acres per Well	Total Oil Production to July 1, 1924	Estimated for Tract	Total Ultimate per Well	Production, Barrels per Acre
A	43.5	10	4.35	1,900,000	4,245,000	424,000	97,500
B	27.5	42	0.66	11,945,000	13,546,000	322,524	492,200

Further evidence of the effect of well spacing on ultimate production is given by a U. S. Bureau of Mines Report on the Hewitt field, Oklahoma, pages 31-35 and page 115. This report cites an example of two ten-acre tracts in the Hewitt field, one with four wells and another with one well. Underground conditions were as nearly comparable on the two tracts as could be expected in an oil field. The report states:

Examination of the curves in Fig. 6 brings out that the recovery per well will be almost two times greater when one well is drilled to 10 acres than when four wells are drilled to 10 acres. However, the recovery from 10 acres is almost two times greater when drained by four wells than when drained by one well.

The final result, then, of producing with wells too widely spaced is that excess gas is used in bringing oil to the wells and much oil is left in the sand. In addition we believe

there would be some further loss of oil from wide spacing, because drainage by gravity would be less efficient than if the wells were closely spaced.

Gas as it Affects Oil Production.—Undoubtedly gas is the principal factor affecting production in the early life of most fields. It causes the expulsion of the oil from the reservoir rock and causes the well to flow. In order to obtain the most efficient use of gas, there are at least six closely interrelated factors, the control and dependency of which, one to the other, is not clearly understood, but which have been made the subject of much careful investigation. These are: (1) size of tubing in the well; (2) depth to which it is set; (3) height of fluid level to be maintained; (4) back pressure; (5) casing pressure; and (6) depth of well. As the correct evaluation of these factors becomes better understood and the minimum quantity of gas used to produce a maximum amount of oil, a slower drilling program and wider spacing of wells may be found to produce, perhaps at a slower rate, the same or better results than are now obtained by the closer spacing and more rapid drilling programs.

If an oil sand is very coarse or the reservoir rock is of the cavernous limestone type, the oil is more easily expelled from the formation and fewer wells would be necessary than where the pore-space is small. Heavy viscous oils will require a closer spacing for maximum recovery than will the lighter more fluid oils. Naturally, shallow, thick oil sands will warrant somewhat closer spacing than would thinner sands or producing horizons at great depths.

Due to the combined effect of viscosity, surface tension and the size of the voids, there will come a time when the oil remaining in the sand after all effective gas is produced will reach an "angle of repose." Between each group of wells there will be a cone-shaped volume of oil. If the spacing is sufficiently great and the oil of sufficient value, it might pay to drill wells more or less midway between the other wells.

Rapid Drilling and Recoveries.—The following is quoted from an article prepared by petroleum engineers of the Standard Oil Company of California, which appeared in the Standard Oil Bulletin for December, 1923:

Statements made by Cutler and Clute of the U. S. Bureau of Mines lend a favorable opinion toward greater recoveries in the Oklahoma fields by more rapid drilling programs:

Naturally a loss in recovery per acre follows a delayed drilling program owing to the smaller initial production of wells and also in some cases to the effect of drainage. The drainage factor is important to the operator if his property has not been protected properly by line wells. In order to obtain the maximum amount of oil for a district, a fast-drilling program is necessary, thus obtaining wells of relatively large initial production and consequently large ultimate production.

Data showing the effect of time of drilling on ultimate recovery are given by the above authors in several Oklahoma pools. These data indicate that losses were sustained ranging from 5% in two years to 33% in one year on account of delay in drilling. Statements are made by Swigart and Schwarzenbek to the effect that in the Hewitt Field, Carter County, Oklahoma, an estimated loss was sustained of 53% on account of delay of one and one-half months, and another instance of a loss of 73% due to a delay of four months in drilling. Lewis and Beal are authors of statements to the effect that one well in the course of time may drain out all the gas in the field almost as completely as 100 wells, but the amount of oil drained from the field will be far less than if the hundred wells had been drilled. Practical examples of this statement may be noted from an examination of the production records of fields throughout California. Previous to the time that wells were drilled on town lots the more closely drilled fields, such as McKittrick, Brea-Olinda and Kern River, were higher in recovery per acre than most other fields. These three fields have about one well for every two and one-half acres of developed land, and up to July 1, 1923, according to Collom and Barnes, the production by fields was as follows:

	Barrels per Acre
McKittrick.....	77,700
Brea-Olinda.....	99,400
Kern River.....	39,000

The new fields are now forging ahead on recoveries per acre on still closer spacing in many portions of each field. Up to July 1, 1923, these new fields have shown recoveries as follows:

	Barrels per Acre
Santa Fe Springs.....	73,700
Long Beach.....	102,500
Huntington Beach.....	35,000

A comparison of the foregoing results from closely drilled fields with the production from three other fields, given below, where spacing is much wider with one well to every six or ten acres, is significant:

	Barrels per Acre
Coalinga.....	25,400
Elk Hills.....	22,700
Midway.....	20,500

Lewis and Beal further state that "spacing is not so much a problem of how many acres a well will drain as it is a problem of obtaining the greatest possible production in the minimum time and at a minimum expense."

In a press notice, dated October 29, 1923, the Department of the Interior has made statements on this subject following an investigation by the Bureau of Mines engineer as follows:

Theoretically the closer spacing, the greater the ultimate recovery of oil from oil sand.

Speed in getting a well into the pay sand is a prime requisite, because the first well in any locality benefits by obtaining the flush production. It often happens that a well will produce more oil during the first ten days or two weeks than can afterwards be pumped in a year or more.

Although oil can be recovered more rapidly and in larger amounts with a greater number of wells, if they are drilled before the gas pressure is reduced, too rapid exhaustion of oil and gas may cause the approach of edge water.

The Bureau of Mines has shown that delay in drilling shows a loss in recoverable oil because of reduced gas pressure. It has also been pointed out that widely spaced wells have a larger ultimate production, but the production per acre, as a whole, is much smaller than when wells are closely spaced. It is, therefore, just as important not to overspace wells as it is not to space them too closely. Overspacing decreases the amount of recoverable oil—underspacing usually causes financial loss.

Although the Government is anxious to have the maximum amount of oil recovered, it realizes that an economic balance must be struck whereby the cost of recovery is not excessive with respect to the value of oil recovered.

From the above statements, it will be noted that various authorities are in agreement that to obtain a maximum yield the recoverable oil should be secured as quickly as possible and by relatively close spacing of wells.

Decreased Production from Delayed Drilling.—California has several outstanding examples of decreased ultimate productions through delayed drilling. Naval Reserve No. 2, in Buena Vista Hills fields is one of the best-known examples and is a matter of public record. In this field certain sections of land were retained as a Naval reserve until 1920, when they were leased for development. These sections were surrounded by land that had been drilled and exploited continuously over a ten-year period prior to leasing of the Naval reserves. Wells recently drilled on the reserves have had much lower initial productions and will have much lower ultimate productions than wells drilled on adjacent lands several years ago. Gas pressures have been found to be lower than initial pressures of wells drilled in previous years. The Naval reserve lands were as favorably located as regards structure and were "checker-boarded" with the other lands so the comparison of results is entirely fair.

In the appendix to the Group Report from California is an article prepared by engineers of the Standard Oil Company on the subject of the economic spacing of oil wells. A portion of this discussion is a purely theoretical treatise of the subject but it is interesting to note that while the close spacings do not give the greatest financial return, they always show a greater ultimate recovery.

Waste of Oil and Gas.—Gas is produced with oil in varying amounts from all oil fields. The quantity of gas produced varies from practically nothing to billions of cubic feet per day. In some fields there is an enormous excess of gas per barrel of oil, as these products exist in the natural reservoir. In most fields, this gas is intimately mixed with the oil. A few fields produce gas free, or almost free, of oil in the higher parts of the structure. The gas is certainly

the principal factor which causes the movement of oil to a well and makes it flow.

Before taking up the detailed discussion of the relations of gas to oil and its value as an expulsive agent, brief mention will be made of the intrinsic value of the gas. The intrinsic values of the gas may be classed as follows:

(1) For commercial purposes, such as light and fuel in various industrial plants and for public utility uses.

(2) For power purposes in the oil fields, such as (a) fuel for pumping and drilling wells, (b) fuel to run compressor and absorption plants, (c) fuel for pipe line pumping plants.

(3) For its gasoline content, which is obtained in the absorption and compression processes. Most oil field gases contain so-called soluble hydrocarbons, most of which is classed as "casing-head gasoline." The casing-head gasoline varies from a trace to five gallons, or even more, per thousand cubic feet of gas.

The monetary value of gas in the producing field varies at the well from 4 to 6 cents per thousand cubic feet. The value of wet gas for its gasoline content after deducting the cost of compression and absorption ranges from practically nothing to 60 cents per thousand cubic feet. Probably the average gas contains from 1 to 2 gallons of gasoline per thousand cubic feet (average in U. S. for 1924 was 1.4 gallons per thousand cubic feet) with a value, after deducting costs, of 10 to 12 cents.

If no gas were present with the oil, oil would naturally be the logical fuel to supply power and light for the various oil-field purposes above enumerated. In most cases gas is present and it constitutes a valuable asset in the producing business. Without the gas the average cost of production of oil would be greater and the available supply of oil for market somewhat less.

In fields where natural gas is present as a gas or is absorbed in the oil, it is necessary to produce gas in order to recover the oil. It is readily apparent that it would be

physically impossible to produce oil under these conditions without the gas, and there is no diversity of opinion on this subject. It is generally conceded that in practically all the oil fields gas is the most important factor in moving oil through sand or other porous bodies to a well. It is true that hydrostatic pressure and gravity are other factors which assist in this same movement, but they may be considered as negligible in the flowing period of a field when the gas pressures are high. Observation shows that gas is produced both when the wells are flowing and later when the field is so nearly depleted that production is no longer commercially profitable.

While it is necessary to produce gas with the oil, there is unquestionably an important relationship between the amount of gas produced and the number of barrels of oil lifted. This oil-gas ratio is at present the subject of a great deal of attention and study by many operators.

During the development of some of the highly productive oil-gas fields, claims have been made that oil and gas were wasted due to the rapid development of the fields. No one denies that in the early life of these fields, before marketing facilities were available, large volumes of gas escaped into the air. But this gas performed an important work in moving the oil to the well and causing the well to flow.

In regard to the loss of oil under methods of production now in vogue throughout the United States, no claims of waste can be supported.

We believe that any excess of gas per barrel of oil produced under methods of production common in the past has been of real importance only during a comparatively short time in the early life of a field. Because of the relatively low value of the gas as compared to the oil it has not always been economical to construct the necessary pipe lines and facilities for handling the peak production of the gas which lasts only for a few months. There is a definite limit or radius within which gas can be transported and supplied economically. Gas is the most expensive of oil-field products to

handle, and it has been demonstrated that gas, per heat unit, costs much more than oil.

As soon as development in oil-gas fields demonstrates that there will be sufficient gas to warrant the expenditures, absorption and compression plants are constructed to handle the gas from the wells. The initial costs of such plants are large and considerable time required for their construction.

The industry has always recognized the loss of gas and is carrying on extensive and expensive investigations and is developing new producing practices (*a*) to conserve as much gas as possible in the formations; i.e., to keep the ratio of gas to oil produced as low as possible; (*b*) to return dry gas from compression and absorption plants back into the oil-gas producing strata for the purposes of conservation and increased oil production; (*c*) to so locate wells with respect to structure that the gas-oil ratio may be kept as low as possible.

Nature's "Cracking Process."—The oil and gas as found in the majority of structures are contained in minute voids in the reservoir-rocks. Analysis of oil discloses that it is composed of a very large number of hydrocarbons having an ascending scale of hydrogen carbon ratios. Complete analysis of the gas also discloses that the gas contains hydrocarbons still extending this series of hydro-carbon ratios until the ultimate is reached in the hydro-carbon methane. It is quite generally believed by chemists that there is a slow cracking process going on with all types of carbonaceous material buried in the earth. This process of chemical disintegration, or cracking, involves a change to greater volume at uniform pressure or an increase in pressure if the volume is fixed. It is this action, combined with the compression of the reservoir rock due to settling of the overlying rock mass, and the decrease in void space due to deposition of salts from water which builds up the pressure in closed oil-gas structures.

Function of Gas Pressure.—The function of gas pressure in moving oil to a well is explained by S. J. Dickey of the General Petroleum Corporation, as follows:

Let us visualize the conditions existing in the structure at the initial stage of production of a well on that structure. The well casing has penetrated into the structure, but without any lowering of pressure. The oil and gas existent in all microscopic voids throughout the structure is in a quiescent state without motion in any direction. The pressure in the well casing is lowered by attempting to bring a well into production. When this lowering in pressure takes place there is a differential pressure set up between the location of an oil and gas content void near to the well casing and the casing. Whenever a differential pressure exists between two points and there is freedom of movement of material, the material will move to the point of lower pressure.

Let us consider one particular horizontal direction away from the well casing, and consider this as an alignment of void cells, each in communication with the other along this straight line. At the beginning of production each cell contains the same amount of oil and gas. The contents of the cell nearest the perforated well casing will expand and occupy a new volume corresponding to the new pressure. In doing this an increased gas space is necessary, and to allow for this a portion of the oil in the cell must be displaced and so discharged to a lower pressure point, together with a portion of partially expanded gas.

The next void cell beyond this first cell also is brought to a lower pressure, and it will discharge a portion of its oil and gas through the first cell, and so on successively back in the structure, the cells farthest from the casing being lowered the least in pressure. The cell nearest the casing acts as a conductor for large volumes of oil and gas.

As the structure, after considerable production, gradually lowers in pressure, the space in the voids occupied by free gas must necessarily be increased, and this increase in space must be equivalent to the oil discharged. As this condition goes on the free gas in its compressed state in the voids, acts in the nature of gas in a compressor receiver, and gas will continually move out of such storage receiver with further reductions in pressure.

When the major volume of oil in the cells has been expelled, oil will still remain due to the absorptive nature of the mineral matter, viscosity of the liquid and capillary action. In other words, some oil will remain on the surface of the sand grains, and in minute trapped cells. In the portion of the structure nearest to the well, the expanding gas in flowing through voids still containing some oil, must by its movement mechanically pick up some of this oil, scrubbing it from the surface of the mineral matter and carry it along to the well.

If the release of pressure, particularly during the initial stages of production, is extremely rapid, then very high differential pressures in the structure must be set up, and due to such high pressure losses there must be a great tendency for the flow to seek channels of lower resistance, and

in these channels of lowest resistance, where the flow is concentrated, the high velocities must wash and break larger pathways so that subsequent production of gas and oil from any point will migrate toward the nearest channel, seeking the low pressure pathway instead of uniformly working its way through each successive void toward the well.

It is readily seen, therefore, that considerable potential energy must be lost in conveying the oil from the structure to the perforated casing, due to the loss in pressure in flowing through the successive restrictions. It can also readily be seen that if the withdrawal of the oil from the structure is rapid, or should there be a great differential pressure between the structure pressure and the perforated casing, much greater energy loss will be occasioned per barrel of oil, than if the structure is drained slowly and the differential pressure kept to a minimum.

The relative amount of gas and oil which together enter the well casing through the perforations is dependent primarily on the total absolute pressure condition in the casing next those perforations.

If the perforations are in communication with a homogeneous and fine cellular structure, the only possible control of the ratio of gas and oil reaching the casing is the control of the pressure at that point. As the compressed bubbles of free gas in the structure expand to a lower pressure controlled by the casing pressure, the gas in the expanded portion moves into the well, leaving the open space in the void filled with compressed gas at the new pressure, and a portion of the oil moves out of the void into the well at the new or lower pressure in the well casing. Some of the gas which was dissolved in that particle of oil in the structure is now released because new conditions are now existent which only permit of a lowered gas content. This released gas will be released into the well.

The amount of gas, therefore, which will come into the well is dependent on the pressure. For casing pressures very close to the structure pressure only small quantities of free gas will be released into the well for a unit of oil, and the oil in the casing will contain a maximum of dissolved gas which, from tests in some structures has been shown to be the lesser proportion of the total gas.

And conversely, if the casing pressure is very low there will be a large quantity of free gas expelled with a unit of oil into the well.

If, however, the perforations tap channels in open communication with gas pockets or reservoirs in the structure containing little or no oil, then gas will be discharged from these pockets according to the lowering pressures in the structure.

Under initial flowing conditions in a well which has been tubed with an eduction or discharge tube, the pressure of the gas and oil in the annular space surrounding this tube must be greater than the pressure at any point on the inside of said eduction tube if the well is to flow and produce oil through this tube. The flowing in such a manner is simply a balancing

of hydrostatic columns or heads, the pressure on the outside of the lower end of the eduction tube being due to the static column of any oil above it, plus any casing or gaseous pressure superimposed on top of the static column of oil.

On the inside of the eduction tube the pressure must be less than that just mentioned; it is equal to the static column of oil in the eduction tube, taking into consideration its lightened condition from gas voids throughout its length, plus any losses in pressure mechanically imposed at the top of the eduction tube.

It can readily be seen that the nearer the pressure at the bottom of the eduction tube approaches the structure pressure, the greater the proportion of initial stored energy available for lifting oil to the surface of the ground, and the lower the proportion of losses in moving the oil from the voids in the structure to the well.

This is, of course, a condition coincident with low immediate rate of production, but is a fact bearing on the efficiency of energy consumption throughout the entire possible flowing period of a well. It is occasionally the case, however, that such casing pressures rise to a point of questionable safety of the mechanical structure and fittings constituting that casing, in which case it is the practice to bleed gas from this casing for safety. All gas so bled off without coincident production of oil, must occasion an energy loss and this energy can never be used in raising oil to the ground.

Considering a given oil viscosity and a given size and length of eduction tube, the rate of discharge of fluids in the eduction tube is dependent on (a) the differential pressure from the bottom to the top of the eduction tube, and (b) the lightening of the column on the inside of the eduction tube due to the actual space in the eduction tube occupied by the gas. The space occupied by the gas is the controlling factor in such a gas lift and not the number of cubic feet of gas in such space, measured and quoted as expanded to atmospheric pressure.

For example, if we should consider a condition whereby on the outside of this tube there was a differential pressure between the base and top of a 20-foot section of tube, equal to a column of oil 20 feet in height, and if on the inside of the tube there was a piston-slug of oil 10 feet in height, and a piston of gas 10 feet in height below this slug of oil, there would be little difference in propelling effort, whether the 10-foot space was filled with gas at 15 pounds pressure or whether this same space was filled with gas at 150 pounds pressure. But metered at atmospheric pressure, the latter gas volume would constitute a much larger volume than the former, and since in each case the same piston-slug of oil is ejected by the gas, the ratio of gas to oil would be much larger with the high pressure piston-slug of gas.

Edge and Bottom Water.—Edge water, as that term is used in oil field practice, may be defined as water found in a stratum or series of strata which, at a structurally higher elevation, contain oil. It is not uncommon, particularly in California, to find water in strata between productive oil horizons on the flanks of an oil-producing structure. In some cases this water, which is termed intermediate water, is in reality an edge water, for the reason that if the strata carrying this water were followed up the dip they would be found to contain oil. This condition is common along the zone of water encroachment, where the oil-bearing horizon consists of a thick series of strata (frequently not uniform in texture). In all California fields edge water is present. It cannot be exhausted by flowing or pumping methods. The rapidity of its flow to a well is variable and it occurs under a wide range of hydrostatic head. As the oil is exhausted, there will be an encroachment of edge water. Whether or not this encroachment will in the end envelop all the field, or fail before it reaches the higher part of the structure, we do not know. Its encroachment can be controlled to some degree, and if the advance is kept uniform structurally, the ultimate result to the recovery of oil from the entire field will be beneficial.

The danger in edge water encroachment, is that its advance may become irregular due to the fact that oil horizons vary in texture, porosity, and consolidation. Some beds are more productive of oil and gas than others. Because of the variation in the coarseness of the sands, some of them will permit fluids to pass through them more readily than others. The oil will be drawn more rapidly to the wells from this particular sand or sands. Also as edge water encroaches, it may advance in such strata more rapidly than in the finer, more compact strata. Another condition which has been noted in studies of edge water is that one or more wells a considerable distance up the dip from the general line of edge water encroachment will go to water; or a well or small group of wells will show practically no

water, although surrounded by other wells producing edge water. The U. S. Bureau of Mines, Bulletin 195, page 72, shows conclusively that in a container filled with sands of varying degrees of coarseness and saturated with oil, flooding with water left the oil in the tight or finer grained sand, but displaced the oil in the coarser sand. In other words, water in its movement displaces the oil more rapidly from the coarse sand. Eventually the oil will be forced out of the finer grained sand also, but under field conditions, the operator would find bodies of oil-saturated, fine-grained sands completely surrounded by coarser sands carrying water. A good example is the East-side Coalinga field, where a small group of wells of the Standard Oil Company produced oil with little or no water, whereas wells drilled somewhat higher up the dip, but in the immediate proximity of the Standard wells, produced water from the same beds.

In all oil fields where edge water occurs in large volume, its encroachment is indicative of the exhaustion of that part of the field. Where it is found that the advance of edge water is irregular, corrective measures should be applied to shut off this water in the particular sand in which it occurs and so protect the sands above and below. Such conditions are understood and taken care of as far as possible by efficient operators. Considering the question of encroachment of edge water as a whole, if its advance is regular and retarded as much as possible throughout the productive measure, its flushing effect for the entire field, as well as for any given property in the field, cannot be considered detrimental.

In the Mid-Continent District the majority of opinions on edge water agrees that where properly regulated it can be used to advantage and will considerably increase ultimate production by present methods. Aside from the replacement of oil in the sand adjacent to the producing wells and the carrying of this oil to these wells, water appears in some instances to transport oil from outside the developed portions of the field to the wells. Drilling is confined in most

fields to the areas where paying wells can be developed. Outside such areas in many cases, is a zone which has a relatively lesser amount of oil but which if taken as a whole may contain an important amount. Edge water transports such oil to the developed portion of the field from areas which at present would not pay to develop.

Opinions from Texas on edge water encroachment also demonstrate that the majority of operators believe this encroachment on the whole is beneficial, after such encroachment is properly regulated, although it may be that in some cases it is harmful to edge properties.

In the Pennsylvanian and Eastern districts, along with the usual increase in recovery from present producing wells, which edge water encroachment is responsible for, many abandoned oil wells have again become producers. Here, again, is an instance of the flushing and transporting agency of edge water. These older wells, being on the upper part of the structure, had gone dead because the oil would not flow into the wells even where vacuum had been applied, but when edge water was allowed to encroach on the field it appears to have carried the oil from other portions of the field into these wells, so that oil in paying quantities was produced along with the water.

Bottom Water Detrimental to Sands.—Opinions from all districts on this subject are nearly unanimous in agreeing that bottom water, if permitted to enter oil and gas-bearing sands, is usually detrimental. This is particularly true in the earlier life of the field, especially if the bottom water is under high hydrostatic head. If the water is under a greater head than the overlying oil, it will naturally enter and flood these sands. In the case of very high oil and gas pressures which are permitted by drilling to come in contact with low pressure water-bearing sands, considerable amounts of oil may force themselves back into the water sands, especially if the well is partly choked in.

Another feature is common in connection with bottom waters in some of the few Mid-Continent fields where this

menace occurs; this is called "coning." Where the well is deep enough to reach bottom water, the water comes up into the sand and forms a cone of water with its apex at the well. This water shuts off to a large degree any oil which would otherwise flow to the well. In such instances it is necessary to keep back pressure on the well to reduce this coning effect.

The general conclusion in every district is that edge water as a general rule is beneficial, and that while it must be controlled, it can be used not only to further the recovery of oil from sands in the field proper, but can be used as a means of bringing oil from outside of the developed part of the field to the field proper, and in this way recover oil from areas which otherwise could not be made to produce economically.

Back Pressures on Producing Wells.—There is a wide diversity of opinion within the oil-producing industry regarding back pressure on producing wells, as a means of conserving gas, producing oil more efficiently, and obtaining a greater ultimate recovery. Before discussing this question mention should be made of two conditions where the use of back pressure is generally conceded to be of value. (1) It has been recognized in Mid-Continent regions to have a value where water immediately underlies the oil in a well, and the well has a large producing back pressure which will prohibit the coming up of water, whereas, if back pressure were not applied the water would come into the hole and have to be raised with any oil brought to the surface. (2) In districts where the producing sands are unconsolidated and have a tendency to cut out the screen and connections, a certain amount of back pressure is beneficial.

Regarding the application and maintenance of back pressure on producing wells as a means of more efficient and greater recovery, T. E. Swigart and E. E. Templeton, both formerly of the United States Bureau of Mines, make the following statement in an analysis of this subject prepared for this report:

Experiments and field observations have led us to believe that if back pressure is properly held on the oil sand at a time when field pressure warrant, we would expect to obtain a smaller amount of gas produced per barrel of oil with an accompanying greater ultimate yield of oil. This practice probably would be beneficial only if applied over large tracts. We would call attention to the fact that back pressures indiscriminately applied without a study of field conditions and of results obtained by various amounts of pressure, will not accomplish the desired results and in all probability will decrease the daily oil production.

The best practice in the matter of back-pressure is probably to be found in California, where back pressures on producing wells has been the rule for years. On studying California wells certain operating conditions must be borne in mind. First, most flowing wells are tubed and the flow of oil and gas takes place through tubing of sizes ranging from 2 to $4\frac{1}{2}$ inches in diameter. Second, back pressure is held on all large flowing wells by beans or chokers in the flow line. This is an acknowledged measure of precaution to protect the well from mechanical damage, that otherwise might be caused by high velocities and soft, shifting formations. Third, pumping wells are not pumped down to a point below the top of the oil sand immediately after they are put to pumping. California wells maintain higher oil productions for a much greater length of time than do Mid-Continent wells. To retard the entrance of sand to the well and cause more steady operation, pumping wells are tubed at distances of from about 500 to 1500 feet above the top of the oil sand for many months.

However, it may be repeated that although for many years back-pressure had been held on California wells during a part of their life, the idea of reducing the gas-oil ratio by back-pressure control has only recently been given serious attention.

Back Pressure and Gas-oil Ratio.—Field observations in California and Wyoming have shown that increasing back-pressure on the flow lines of wells by using small beans will not necessarily reduce the gas-oil ratio. In Salt Creek field, Wyoming, this practice many times increased the

gas-oil ratio by as much as 50 to 100%. Other times increasing the back pressure decreased the gas-oil ratio. To increase the back pressure on a large flowing well that is flowing steadily is usually undesirable as it will decrease the daily oil production. However, there are many examples in California of wells being increased in daily oil production by reducing the size of the beans. If wells have declined so that they do not flow steadily but "surge" or even flow by heads, a smaller bean often will result in a uniform flow and a greater daily oil production.

During the period of over-production of Santa Fe Springs, California, in 1923, it was desired to find out how much daily oil production was being obtained from a well flowing open as compared with the production of the same well after it had been "choked." Records show that upon opening up such a well gas production was increased over 100% without increasing the oil production more than 2 or 3%.

In the Dominguez field considerable study has been given to the control of the gas produced with the oil and some changes in methods of handling wells are being made to reduce the gas-oil ratio. Records show that from new wells producing under high pressures, just as much oil can be produced daily through the same size tubing with 1,000 cubic feet of gas per barrel of oil as with 3,000 cubic feet of gas per barrel. In fact some of the best wells have produced over periods of a month or more with gas-oil ratios of less than 400 cubic feet per barrel.

Two groups of wells at Dominguez illustrate the effect of flowing wells against high and low pressures. Most of the wells experimented with have 3-inch or $2\frac{1}{2}$ -inch tubing. Wells with $4\frac{3}{4}$ -inch flow string were large initial producers but differences in casing-head and tubing-head pressures were comparatively small. Gas-oil ratios in the large flow strings were not excessive, although they were about twice the gas-oil ratios of other wells with 3-inch tubing. The following tabulation compares some of these wells:

Well	T. H. P.	C. H. P.	Difference in Pressure,	Cubic Feet Gas per Barrel Oil	Oil Production, Barrels, Daily	Size Flow String, Inches	Time of Reading
X	315	350	135	1740	4466	4 $\frac{3}{4}$	Initial
	425	550	125	1586	1927	4 $\frac{3}{4}$	End of 1st mo.
Y	160	350	190	595	4297	4 $\frac{3}{4}$	Initial
	325	450	125	1820	2615	4 $\frac{3}{4}$	End of 1 $\frac{1}{6}$ mo.
Z	270	390	120	735	5757	4 $\frac{3}{4}$	Initial
	300	460	160	1360	3743	4 $\frac{3}{4}$	End of 1 $\frac{1}{2}$ mo.
S	160	650	470	473	2940	3	Initial
	175	560	385	653	2275	3	End of 1 $\frac{1}{2}$ mo.
T	145	880	655	338	3950	3	Initial
	170	770	600	527	2900	3	End of 1 $\frac{1}{6}$ mo.
U	150	1025	875	462	3010	2 $\frac{1}{2}$	Initial
	170	970	800	610	2575	2 $\frac{1}{2}$	End of 1 $\frac{1}{6}$ Mo.

The six wells compared above are all in the same general area and were completed within a period of approximately one month. While much larger quantities of oil have been extracted from the wells with 4 $\frac{3}{4}$ -inch flow strings in a short time, their declines are much more rapid and their efficiencies much less, than wells with 3-inch tubing. It should be pointed out also that the wells with 3-inch tubing are offsetting the wells with 4 $\frac{3}{4}$ -inch flow strings, hence are suffering some from the rapid reduction in gas pressure by these large wells.

Four wells in Long Beach field, California, flowed until the casing pressures dropped to as low as 60 or 80 pounds per square inch. Upon lowering tubing several hundred feet in these wells, casing pressures were built upon to as much as 350 pounds and tubing pressures up to around 50 pounds. With the new pressures the wells came back flowing from 200 to 500 barrels. From this information it is

concluded that by maintaining back pressure on the sand, even in territory which is pretty well depleted, flowing production may be increased. The gas production was metered on one of these wells and it was found that the gas-oil ratio was less after lowering tubing than before. This indicates that aside from the additional production obtained by flowing, a greater ultimate production may be expected from wells so handled.

Experiments with back pressure have been made on pumping wells which have declined to productions as low as 10 to 20 barrels per day. The results show that by holding back pressures on these wells the amount of gas produced was very materially cut down. While too much back pressure reduces the daily oil production by about 15%, the oil-gas ratio and therefore the efficiency of recovery was increased two- and three-fold.

In a report by T. E. Swigart, entitled "Experiments on Back Pressure on Oil Wells," published by the U. S. Bureau of Mines, the results obtained from experiments with back pressure in two pumping wells in Osage County, Oklahoma, are described. One well pumped 450 barrels of oil per day, with a back pressure of 370 pounds per square inch on the casing head. Over a period of four days the gas-oil ratio was 550 cubic feet per barrel. The following three days the well was pumped without back pressure on the casing head. The oil production averaged 450 barrels per day but the gas-oil ratio increased to 750 cubic feet per barrel. Similar results were obtained in recent tests at Long Beach, California.

The *Oil Weekly* during March, 1925, published a report by T. E. Swigart entitled "Notes on the Efficiency of Flowing Wells, Dominguez Field, California." This paper contains detailed information on the flowing wells at Dominguez Hill, California, and describes certain observations and deductions from these data. In short the paper points out that apparently a relation exists between the gas-oil ratio of a well and the difference in the pressure at the tubing

head and the pressure at the face of the oil sand in the well. The greater the difference between tubing head pressure and working pressure at the oil sand level the smaller appears to be the gas-oil ratio and the more efficient the well. A study of many records indicates that this relation does not always exist from day to day or even from month to month, but in general the relation is borne out by most of the data available.

As a result of this work the tubing has been lowered in one well to a short distance below the top of the perforations in the oil string. The oil production increased slightly and the gas production decreased slightly. The casing head pressure increased from 220 to 275 pounds. The results of these experiments however have not been decisive enough to substantiate in full the relation suggested in the report. As pointed out in previous paragraphs, however, the lowering of tubing in four Long Beach wells has borne out the contention made in this paper and it is hoped that further experimenting at Dominguez will show the desired results there as well.

Another problem in this connection on which there is no definite information is how much oil might be recovered from a field by gravity and in the end by natural water flushing if no attempt was made to hold back the gas. No doubt these conditions vary in different fields. In some of the oldest California fields, such as Pico Canon, Newhall and Kern River, some gas still comes off with the oil although the wells have been opened up wide and pumped for the past 15 years. In these and many other cases some gas is retained in the oil in the interstices of the sand for many years when no back pressures have been held on any of the wells in the field.

Comparatively high back pressures should be held against the oil sands while field pressures are high, but a low pressure should be held on the tubing head. High back pressure on the oil sand tends to prevent gas from by-passing oil in the sand, and thus to cause gas to bring more oil to the well.

Tubing pressures should be low because they operate against the natural " gas lift " and if they are too high they will hold back the fluid.

It cannot be proved that the ultimate production of a well producing 3,000 cubic feet of gas per barrel of oil will be one-third the ultimate production of a well producing 1,000 cubic feet of gas per barrel, but from present evidence it is indicated that wells with excessive gas-oil ratios will produce considerably less oil. Back pressure should be maintained on all wells in California fields, while field gas pressures are high, but the well pressure obviously must be less than the field pressure, else the oil will not flow to the well. The determination of the proper differential pressure between the well and remote parts of the sand is difficult to ascertain but seems to be the governing factor in the efficiency of production.

At the present stage of development in oil-producing methods the only manner by which the proper back pressure can be determined is by experimentation. Possibly further study might enable an operator to determine the answer to this question by mathematical formula, but this does not seem likely because of the many varying factors that bear on the production of oil and gas.

OIL LEFT IN SAND AFTER FLOWING AND PUMPING CEASE

AMOUNT OF OIL LEFT IN SAND

It is generally believed by the majority of oil technologists and geologists that from 20% to 40% of the original amount of oil in an oil sand can be extracted by our present flowing and pumping methods. There is, however, some diversity of opinion on this question, especially among practical oil men. Numerous statements have been published by geologists and engineers as to the amount of oil which can be extracted by flowing and pumping. No attempt will be made to quote all of the authorities, but most of the estimates range from 10% to 50% laboratory experiments on completely saturated oil sands show that from 12½% to 85% of the oil, depending on the viscosity of oil and the texture of the sand, can be recovered by gravity flow. The average obtainable by gravity is approximately 25%.

A large percentage of oil remains in the sand after the wells have been completely exhausted, in oil fields where the productive horizons consist of sands or sandstones, or where the pore-spaces are small. In the so-called Golden Lane of the Tampico District, Mexico, where the oil occurs in a cavernous limestone, the percentage of oil left in the reservoir may be as low as 10%. In general, the smaller the pore-space the smaller the ultimate recovery by flowing and pumping.

One interesting example in this connection, where the facts seem to have been clearly determined, is at Pechelbroon, Alsace. In this field, after wells had produced for ten years, mining methods were introduced and it was shown that approximately 60% of the total amount of oil still remained in the sands.

Experiments in Gravity Flow Recovery.—R. C. Collom, U. S. Bureau of Mines, experimented on sands obtained from

the Burkburnett oil field, Texas, with an oil at 36° A.P.I. and was able to recover from 20 to 21% by gravity flow. Another group of experiments of the same kind are reported by J. O. Lewis in U. S. Bureau of Mines Bulletin 140, page 23, as follows:

In these tests glass tubes $1\frac{1}{2}$ inches in diameter and 20 inches in length were tamped full of sand, set upright, and the sand saturated by forcing oil up from the bottom. They were then drained at a temperature of 70° F. through a small glass tube at the bottom. The remaining oil was measured after drainage had become extremely slow, and had practically ceased, no further loss in weight being detected in several days. If the draining had been continued over a long period possibly a little more oil would have been removed, but the experiments were carried on until a rate had been reached far beyond what was thought to represent the practical limits of oil production. The experiments were not carried to the greatest accuracy, but are believed to contain no material error. The full range of conditions found in the oil fields was not covered, and both the upper and lower limits may be exceeded, but these figures illustrate the possibilities of oil being retained in this way. The conditions of the experiments, a homogeneous mass of clean sand in an upright tube, are far more favorable for draining in almost every particular than are those ordinarily found in oil sands, and suggest how much oil may be retained when gravity is the sole agent for expelling oil.

How tightly this oil is retained was shown by letting fresh water flow through the tubes of drained sand from the bottom to the top at a temperature of 70° F., for from only one tube was there even a color of oil on the water after it had passed through.

The sand experimented with was a coarse sand, having well-rounded grains of uniform size, average diameter, about $\frac{9}{54}$ inch, and a porosity about 57%, and a finer sand, having angular grains of irregular size about $\frac{3}{54}$ inch average diameter, and an average porosity of 38.5%.

To determine how alternating layers of coarse and of fine sand affect the amount of oil retained, a tube was packed with alternating layers of such sands saturated with oil and then allowed to drain until no further loss of weight could be detected during a period of several days. The results were compared with those obtained by using similar tubes in which only one of the sands was packed. In the fine sand alone, 21% of the oil was retained; with the coarse sand alone, 17%; whereas with the two sands in alternating layers, 35% of the oil in the tube did not drain out. No barriers were interposed between the layers in the two kinds of sand, yet much oil remained concentrated in the layers of the finer sand, its superior capillary power not permitting the coarse sand below to withdraw the oil.

TABLE 3.—QUANTITIES OF OIL RETAINED IN DRAINED SANDS

Oil	Sand	Time Drained, Days	Oil Retained, Percentage of Capacity of Sand
Bradford crude, gravity 41.2° Bé. (0.818).	Coarse	26	15.0
	Fine	26	21.0
California crude, gravity 25.1° Bé. (0.903).	Coarse	42	24.0
	Fine	43	42.0
California crude, gravity 14° Bé. (0.972).	Coarse	73	30.5
	Fine	73	53.0

Other experiments indicated that the ultimate recoveries by water displacement were no greater and, indeed, appeared to be somewhat smaller than by natural drainage even under the favorable laboratory conditions. In these experiments water was allowed to rise through the tubes from the bottom to the top under various conditions of sand, oil and pressure. Always a considerable portion of the oil displaced and flushed from the sand was accompanied by so much water that its recovery would not be feasible in the field. When the experimental conditions more nearly resembled field conditions the oil displaced, unaccompanied by water, was much less, so that the oil ultimately retained in the sand became greater. This was particularly true when the sand had been partly drained before letting the water rise through it, the water showing a marked tendency to bypass and trap the oil.

By forcing compressed air or gas through the tubes greater recoveries were obtained than by natural drainage or by water displacement. With the same oils and the same fine sand as in the above table, only 17½% of the 41.2° Bé. Bradford oil and 28% of the 25.1° California oil were retained, the relative recovery being greater with the heavier oil. After all the oil possible had been removed by the air or gas, the passage of water even under 50 pounds pressure failed to remove as much as an iridescent film of oil from the sand.

At this time no general statements in regard to the efficiency of the recovery of oil under the various conditions can be made, except that it is generally considered to be greater in the deeper sands because pressures are generally greater. However, the smaller cost of producing from shal-

low wells allows them to be pumped to smaller productions, which partly compensates for the greater energy stored in the deeper sands. In small quantities salt water is generally considered to result in greater recovery in the eastern fields in sandstones producing paraffin oils, but in larger quantities it increases the cost of production and cuts short the life of the well. Where a sand is flooded with water, as in a "water drive," the water is almost certain to trap a large part of the oil. The spacing of wells also affects the recovery of oil from the sand, as well as the method of operating them. Commercial conditions are important factors, for, if it were profitable to pump the well down to one-tenth of a barrel a day, as is done in some Pennsylvania fields, obviously there would be less oil left in the sand than if 10 barrels daily were the economic minimum, as for some California wells. The life of a well is terminated at the point where production ceases to be profitable, and not by the complete exhaustion of the oil.

In some recent experiments by the Standard Oil Company of California on a miniature oil field, on which gas pressures as high as 160 pounds per square inch were used, it was found that 12.2% of the oil contained in the miniature field was recovered by flowing.

The porosity of the sands used, determined by filling voids with petroleum ether was 35.1%, 34.8% and 35.6% by volume.

The oil used was a 25.8° A.P.I. Southern California crude of viscosity at 60° F. 280 seconds Saybolt .55 absolute; 100° F. 123 seconds Saybolt .26 absolute.

The gas used in most of the tests was refinery oil gas, with comparative tests made on Midway natural gas. The solubility of the gases in the oil used was determined at a temperature of 60° F. Air was used in place of gas in a few tests.

	Per Cent by Volume
Natural gas.....	44.5
Oil gas.....	67.5
Air.....	25.0

No attempt was made in these experiments to simulate pumping conditions, and it is also probable that a very small additional amount of oil might have been obtained if the experiments had been carried on over a longer period of time.

A. G. Melcher, lately of the U. S. Geological Survey, who has been studying physical properties of oil sands in various parts of the United States, has found that the grains of an average oil sand are much smaller than one would at first think; that their average sizes for many of the important producing sands are between one one-hundredth and one two-hundred-and-fiftieth of an inch and smaller. The openings between the grains in such oil rocks are as small as one one-thousandth or even one ten-thousandth part of an inch in diameter. It is not surprising then that Melcher, as quoted by David White, found from actual determinations of oil and water content on samples from a core taken through the producing sand in the Bradford-Allegheny field in a supposedly watered out area, that about two-thirds of the total oil content of the oil sand remained, the rest of the pore space being filled with water. This means that two-thirds of the original oil content of the sand remained, unrecovered, after flowing and pumping and water-flood methods were all abandoned. In this area more oil is recovered by the water-flood method than by the previous flowing and pumping method. During the life of the Bradford field up to the present time, a period of about 50 years, some 10,000 barrels of oil per acre have been recovered in the acres from which the core tested by Melcher was taken. There remains in the sand still to be recovered at least 30,000 barrels of oil per acre. On the basis of these data White, speaking to the Northwestern Pennsylvania Oil Producers Association in October, 1924, estimated that the Bradford field still contained 2,500,000 barrels of oil.

In a recent analysis of this problem T. E. Swigart and R. R. Templeton state that by present producing methods about 25% of the oil is recovered. Both of these technolo-

gists have had the benefit of experience in the Mid-Continent and California districts, as well as having been engaged with the U. S. Bureau of Mines on this and allied problems.

The average amount of oil remaining in the sand after pumping fails is estimated as follows: .

	Per Cent
Eastern Fields.....	75
Mid-Continent Fields.....	70
Southern Fields.....	50
Western Fields.....	70

The estimated possible recovery of this remaining oil by present known methods, excluding mining, for these same districts is as follows:

	Per Cent, Approximately
Eastern Fields.....	50
Mid-Continent Fields.....	75
Texas Fields.....	50
Western Fields.....	(No definite estimate was given for the Western District, but it is believed that the amount recoverable will be large.)

The above estimates, the average of which may be considered as conservative for the entire country, prove a tremendous underground oil reserve, billions of barrels of which will be recovered when necessity arises.

RECOVERY OF OIL AFTER FLOWING AND PUMPING CEASE

In estimating the nation's oil reserves, the problem of oil recovery has become increasingly important. In fact, in the older fields of the country rejuvenation of depleted properties is more attractive to capital than the drilling of new wells, or the opening of new pools. The quantity of oil to be recovered by improved methods now in use in certain parts of the country apparently will be large, greatly exceeding in some cases the amount of oil recovered through many years of flowing and pumping.

Experience indicates that the amount of recovery by new methods will vary in different formations. Study of

this subject has been confined to few localities and extends over only a short space of time. The limitations of methods now in use are but imperfectly known, and opinions differ as to the conditions necessary for most successful operation.

At this time four methods of oil recovery from depleted oil fields are in use; viz., flooding, air or gas pressure, dewatering, and mining. All of these methods have been successfully used, the first three in this country, and the fourth in France. The amount of oil produced to date by all of these methods combined forms a very small part of the total production, but in the future it is probable that the oil recovered by these means, and others yet to be devised, will amount to a large fraction of the country's production.

Flooding Method.—The recovery of oil by flooding while it has been practised in a limited way for a number of years, is still in its initial stages, and in order that results may be best understood it may be well to give a brief outline of the history of the Bradford field, to show its long decline to the point of abandonment, and its recent rejuvenation.

The Bradford field, one of the country's largest and most important oil fields, was discovered in 1869. Development was slow; in August, 1875, only six wells were producing, and none of these exceeded 10 barrels daily; but in November of that year a 75-barrel well was completed, and following this, wells were completed with initial production reported in some cases as high as 1,000 barrels daily. In 1876 about 380,000 barrels were produced, and the peak was reached in 1881, with an output of 23,000,000 barrels. From that time the decline was steady until 1906 when the low point was reached with an output of 1,922,501 barrels. To date the field has produced about 260,000,000 barrels of oil, or approximately 2,600 barrels per acre. The present annual production is close to 3,000,000 barrels, the recent increase being a result of flooding.

The Bradford field, according to different estimates, includes from 100,000 to 120,000 acres, about 70% of which is in Pennsylvania and 30% in New York. The wide varia-

tion of the estimates is probably due to the exclusion of certain inside barren, or abandoned, areas by one authority and not by another. Of the total area, however, something less than 100,000 acres are now producing, or will yield large recoveries from flooding. Careful estimates place the floodable area at 80,000 acres. There are about 36,000 wells in the field with a daily production, when not effected by flooding, of from $\frac{1}{8}$ to $\frac{1}{2}$ barrel each.

Flooding effects in the Bradford field were first recognized about thirty years ago. Previously there had been some cases of accidental flooding due to improperly cased or plugged wells, and while the beneficial effects were noted, it was not until 1920 that flooding was legalized in the Bradford field alone, by the General Assembly of the state. Since that time more attention has been directed toward flooding, and it is probable that production will increase yearly, until the daily output reaches important figures.

There are several methods of flooding now in operation. Most commonly water is pumped into a central water well around which are drilled oil wells in a circular arrangement. This method is not considered by many as either efficient or economical, and other plans are being put in operation. About two years ago, the Forest Oil Company drilled a central row of water wells, spaced 210 feet apart, on one of its properties. On each side, at a distance of 105 feet from the line of water wells, other wells were drilled so as to fall on a line half way between the water wells. As these wells are exhausted of oil by flooding, they in turn become intake wells for water and the operation is continued.

The recovery from this method, according to Forest Dorn of the Forest Oil Company, is as high as 10,000 or 12,000 barrels per acre, which is more than the previous yield by flowing and pumping. This, however, is a much larger yield than other operators in this district obtain, and it is considered above the average to be expected from the field. Frank Haskell of the Tide Water Oil Company, who has had many years' experience in this field, and whose

company is an important producer there, estimates that the additional recovery from flooding on his leases will be 3,300 barrels per acre. His estimate of all past production from these same leases is 2,600 barrels per acre; in this case, therefore, flooding yielded 126% of the earlier flowing and pumping production. Other operators recover 1,600 to 10,000 barrels per acre from flooding, and the average recovery for the entire Bradford field is placed at 2,500 to 5,000 barrels per acre of floodable land, or 350,000,000 barrels for the entire field.

Robert B. Bossler in Bulletin No. 36, Department of Internal Affairs of Pennsylvania, gives the following results of recovery on properties in the Bradford field:

Number of Property	Acres Flooded	Natural and Flood Production	Natural Production Without Flood (Estimated)	Production from Flooded Area	Production per Acre Due to Flooding
1	2.2	11,748	1,650	10,098	4,590
2	.....	4,137	1,500	3,637	.....
3	90	221,618	49,000	162,618	1,800
4	6	39,022	6,000	33,022	5,500
5	2.6	30,980	1,825	29,151	11,200
6	24	.....	.....	113,000*	4,700
7	24†	77,399	41,200	36,199	1,500?
8	4†	20,168	0	20,168	5,000?
9	.....	6,131	0	6,131	

* Estimated in part.

† Probably wrong.

‡ Estimated.

If the estimates of natural production without flooding are correct, the figures in this table indicate that the yield is greatly increased by flooding. Wells without natural production have been made to yield thousands of barrels of oil, some producing wells have doubled their output, and others have multiplied their previous production many times.

Flooding is expensive, and cannot be done on low-priced

oil. By the Dorn system two wells are drilled on each acre, and as wells in the Bradford field with an average depth of 1,700 feet cost from \$2,500.00 to \$5,000.00 each, it is necessary at the present price of oil to recover large yields per acre. In less productive parts of the field it will be necessary to employ less expensive methods, at least until the price of oil becomes higher.

The prospect of greatly increased production from Bradford field by flooding and other methods has made possible the sale of properties yielding from $\frac{1}{15}$ to $\frac{1}{2}$ barrel of oil per well at prices ranging from \$1,000.00 to \$2,500.00 per acre, or approximately \$12,000.00 per barrel. One property of approximately 105 acres was bought 21 years ago for \$23,000.00 by two men who had spent their lives in the Bradford field. Some time after the purchase an edge well increased production. The owners then drilled other wells ahead of the water pressure, which, as it later developed, was coming from an unplugged well on the adjoining property. In 1923, a one-half interest in the lease was sold by one partner to the other at the rate of \$125,000.00 for the whole property. Within one year, the purchaser of the one-half interest sold the whole property to other experienced and successful oil men in the Bradford field for \$250,000.00. Such instances could probably be multiplied but this is enough to establish the value of water flooding, when it is realized that these transactions were between men of life-long experience in the Bradford field.

Before these old leases can show profit oil must be produced to pay not only high bonus but also the costs of development. Robert E. Bossler estimates the costs on 160 acres at \$1,529,000.00, allowing \$1,000.00 per acre or \$160,000.00 bonus, and \$1,369,000.00 for the drilling of 169 wells. The Dorn system, in which approximately two wells are drilled on each acre, would make development still more expensive.

While flooding has been practised for a number of years,

it is estimated that not more than 10% to 25% of the Bradford field is watered out. Deducting the watered-out area and certain parts of the field that cannot be successfully flooded, leaves 70,000 to 80,000 acres yet to be flushed. The rate at which water travels through the sand varies, according to sand conditions, from 35 to 250 feet per year, averaging about 70 feet. It is estimated by those familiar with the field that it will take from twenty to forty years for the production to reach its peak, which is placed at 30,000 to 50,000 barrels daily. The date of peak production will be governed largely by the price of oil. Should the price remain high enough for a fair profit, production may rise to 30,000 or 40,000 barrels daily within the next three or four years.

Flooding at Bradford is drawing attention to the possibility of its application in other fields. Some authorities believe it cannot be applied successfully to other fields, basing their opinion upon results of flooding in other localities. Others, for the same reason, are convinced that it can be successfully used in the greater number of fields in the Appalachian region. They know of satisfactory results in Pennsylvania and elsewhere. As with anything new, many think that it can only be successful in the place of its origin. These people believe that the Bradford sand is more or less peculiar to itself, and speak of it as a uniform sand. That it is not a uniform sand is shown by cores taken through its entire thickness. It varies greatly both in porosity and in mineral content. The average grain of the Bradford sand is $\frac{1}{250}$ of an inch in diameter, which is about half the size of the average grain of the Bartlesville sand. Whether or not the size of these grains makes it better adapted to flooding than other sands, remains to be seen. The consensus of opinion is that most oil sands will respond to this method of treatment.

Before recovery by this method can be generally practised it will be necessary for the various states to pass laws permitting its use. New York and Pennsylvania are

the only states which permit flooding of oil sands at the present time.

Due to similarity of conditions it might reasonably be expected that the fields of West Virginia and Eastern Ohio will respond to flooding, like those in Pennsylvania. Outside these areas, however, the similarity of conditions is less apparent, and water-flooding effects are only known where water has had access to the oil sand by means of an improperly plugged well, or through a leaky casing. These instances indicate that many sands in various parts of the country, where gas has been the expelling force for oil, will yield additional oil upon flooding, though probably less on the average than in the Eastern fields. While the sands of many fields may be suitable for flooding, there may be obstacles in the way that will cause other methods to be substituted. In a number of fields water supply is lacking, while in others the cost of drilling would be too great to permit Bradford field practice.

Compressed Air or Gas Method.—The recovery of oil by means of compressed gas or air dates back to 1911, when it was first put in operation near Marietta, Ohio. It is known as the Marietta, or Smith-Dunn process. By its use, gas or air is forced into certain wells by means of compressors, and the oil is forced to other wells and pumped out. It was tried at Bradford at one time and found successful as a means to recover oil, but was later abandoned in favor of flooding, due to the fact that enough gas was not available, and the air that was forced into the wells rendered the gas unfit for use.

This method, however, is in use in a number of Eastern fields and promises to add greatly to the amount of recoverable oil. As in the case of flooding, it has not been in use long enough to demonstrate its possibilities, or limitations. In Bulletin 148, U. S. Bureau of Mines, J. O. Lewis states that it has been successful in 80% of the places where used, including 4,000 wells on 100 properties. At the same time, Lewis estimated the recovery by this

method at 50% of the total recovery by flowing and pumping. In the early stages of the use of the air pressure method, failures or low recoveries were due to lack of understanding of the action of air on oil in a sand. Very few, if any, oil sands are uniform throughout their thickness and air forced into a well, if not controlled, will pass through the more open parts to the surrounding wells, carrying very little oil with it, and escaping without building up a pressure. In some cases, wells that began to show an increase of oil due to the air pressure were pumped to their capacity, thus lowering the column of oil in the hole to such a point that the air was permitted to escape instead of remaining in the sand to maintain a pressure. In some plants to-day the air that is forced into a well is metered and controlled so as to force it into all parts of the sand, and thus recover the oil from the fine-grained parts as well as the coarse-grained parts. Lewis states that on properties where it has been in use about eleven years 50% to 200% more oil has been recovered since air was applied than was produced previously.

As an illustration of the favorable results of air pressure on an exhausted property in Pennsylvania, Frank Haskell gives the following data which he states are approximately correct. The year before air was used the production amounted to 2,800 barrels. The year following the application of air pressure with operation full time, the production had increased to 10,000 barrels. An average production of approximately this amount was maintained for eight years, during which time the production never decreased below 9,600 barrels, or increased above 11,000 barrels. During the tenth year of air pressure the production rose to 13,000 barrels, or more than four times the amount produced during the last year of pumping life.

In Bulletin 36, Department of Internal Affairs of Pennsylvania, Bossler gives the following results from the Smith-Dunn Process in Ohio:

INCREASE IN PRODUCTION OF OIL ON FIVE DIFFERENT PROPERTIES IN OHIO
DUE TO USE OF SMITH-DUNN PROCESS
(In Barrels)

Natural Production Before Air	Estimated Subsequent Production Without Air	Total Estimated Production Without Air	Actual Production Since Use of Air	Increase Due to Air		Wells	
				Barrels	Per Cent	Oil	Air
18,308	5270	22,578	27,515	22,245	95	?	?
16,229	2360	18,589	13,672	11,312	61	7	1
16,500	1735	18,235	14,665	12,830	71	1	1
44,660	6350	51,010	42,810	36,460	71	17	5
23,900	4700	28,600	8,930	4,230	14	?	?

The data shown in this table do not represent all of the installations and are not known to represent average results.

Outside the Eastern fields the air-pressure method has been used in a very limited way and in some cases where used it is evident that it was improperly done. Compressed air methods to increase recoveries are economically feasible and are actually being carried out under present prices (March 1, 1925) in a number of pools in Kansas and Oklahoma. Some of these have been in operation for five years, though not at a profit during periods of low crude prices.

Kansas air operations have been confined to the shallow "shoe-string" sands of Franklin and Miami Counties. A plant is now being installed on an Elk County property, and several Chautauqua County operators contemplate early installations. In Franklin and Miami counties near the town of Wellsville, entire shoe-string sand bodies have been placed on air. Daily production at the same time air was applied has been permanently increased from three to five times, with temporary increases for several months as great as ten times.

In the vicinity of Chanute, Kansas, similar results are reported. Here, however, several attempts were abandoned due to faulty procedure. One well completed, after pressure

had been restored to sand by compressed air, flowed. At Erie, Kansas, induction of compressed air into the reservoir gave no appreciable results.

Early attempts to apply compressed air to shallow Nowata County sands failed, due to excessive air pressures applied suddenly instead of being built up slowly. Recent application of air indicates recoveries in line with those in Kansas. Near Tulsa, compressed air has increased production about three times.

Thus far, compressed air has only been applied to properties yielding from $\frac{1}{2}$ to $1\frac{1}{2}$ barrels per well per day. When the air is forced slowly and the pressure built up gradually over months and even years, under skilled technical direction, increased production has warranted installation. Whether the percentage increases (300 or more per cent) would be as great when air pressure is applied to wells making as much as 10 barrels daily, experiment alone will tell.

Briefly stated, compressed air may be profitably applied at present crude prices to all thick, originally highly saturated sands, which have reached the point of abandonment under the pumping system. Such properties, based on Eastern experience covering many years and Mid-Continent experiences covering several years, may be expected to produce as much oil in the future as they have in their previous history, but such production will be spread over a greater number of years.

Unwatering Method.—The third method of rejuvenating old pools is unwatering. Two fields are conspicuous for its use: Tidioute, and the famous Petroleum Center-Pioneer field.

Both of these fields were early discoveries, the holes were drilled usually by the wet method, before casing was developed or thought to be advantageous. Tubing was inserted and water sealed off by a seed-bag packer. As the lower part of the Third Venango sand in these two fields was known to contain salt water it was common practice to drill only into the upper oil-bearing stratum.

At Petroleum Center and Pioneer, excitement was intense and very small parcels of land were sold or leased, resulting in a large number of wells. When these wells declined to a settled unprofitable production they were abandoned, in some cases without removing the material. These wells permitted the entrance of water to the sand and in a short time the field was flooded, the water traveling at the rate of 1 to 5 feet a day.

About 1904 an effort was made in Tidioute to produce oil from the flooded pool. After pumping water for six months and being ridiculed by everybody, the owner began to produce an increasing quantity of oil. At Pioneer an attempt to rejuvenate oil wells was made about 1917. By drilling to the bottom of the sand, by using a large working barrel, and by pumping continuously, the water was exhausted and some gas obtained. In order to accelerate the process and to help carry the expense, a vacuum and compressor was installed, which produced some gasoline.

The present procedure is substantially the same. In the first wells drilled into the sand, the water rose 300 feet above the top of the sand, while later wells encounter no water in the first 15 feet of the pay. The entrance of new water through old holes was prevented by plugging many of them. This was further aided by a natural plugging off by silts and a chemical precipitate locally called gypsum.

This rejuvenation, combined with the manufacture of gasoline, has been highly successful, one 100-acre lease showing oil production as follows:

	Barrels
1919	47,000
1920	56,000
1921	43,000 (last two months estimated)

In addition to this, three gasoline plants were built on this lease, one of which produced 32,000 gallons in November of 1924 and has been averaging at least 500 gallons per day since September, 1919.

Tidioute probably represents the advanced stage in the history of this process. Vacuum is applied universally, new wells drilled in showing "back suction." Oil production has declined to a very small quantity. The continued application of vacuum has so exhausted the methane, ethane, and propane, that no pressure is required to condense the vapors drawn in the vacuum pumps, gasoline being formed at zero to four pounds pressure. Due to the decline in oil production and the increased richness of the gas, gasoline manufacture has become the chief source of income and the wells are kept open and free of water for the gas they contain. This latter fact prevents the use of compressed air for the production of oil in this field.

This method is probably applicable to a number of early fields in Pennsylvania, which were drowned because of lack of knowledge and equipment. The Pithole pool and the Cooperstown or Clade Mill pool are two examples. It would seem that there is an opportunity to take advantage of the considerable water pressure in the flooded sands in these pools. By proper placing of packers, or a system of bottom plugging, this water could be made to force the oil out of the fine-grained portions of the sands in which the greater part of the remaining oil is believed to be held.

Mining Method.—In order to get the greatest recovery possible from an oil-bearing formation it seems that it will ultimately be necessary to resort to mining. In the Pechelbroon region in Alsace, where mining of the oil sand for the recovery of petroleum has been carried on successfully for a number of years, it is reported that after the field had been exhausted by pumping and flowing (17% of the original oil content having been so removed) all but about 8% of the original oil content of the sand is obtained by mining. The method employed here is probably as efficient as will ever be developed for average conditions. Forty-three per cent of the original oil is recovered by natural drainage into tunnels driven into the oil sands; and it is planned later to wash or retort the

saturated sand remaining, by which an additional 32% can be recovered.

In this country methods are being developed and experiments are being made, on types of mining which do not involve tunnelling into the sand, as it is believed that enough gas remains in the sands of this country after exhaustion by pumping, to make work within the sand itself too dangerous for successful operation. In the Pechelbroon mines where the tunnelling method is used, the greatest precaution has not prevented serious accidents. The sand in these mines is unconsolidated; the oil is of low gravity and the gas content is small, while in this country, as a rule, the sands are consolidated, the oil is of high gravity and the gas content is large.

The new methods being considered in the United States contemplate the sinking of shafts to a short distance either above or below the oil sand. Galleries will be extended from these shafts parallel to the sand and from these galleries numerous small holes will be drilled into the sand. These small holes will be tubed and through them oil and gas will be admitted under control into the galleries. To increase the amount of recovery over that which would drain naturally, it is proposed to force air or superheated steam into the sand.

There are many oil fields in this country where the sands lie at comparatively shallow depths, and it is certainly reasonable to assume that some of these methods can be operated successfully when the need for oil is such that the operation can be made profitable. As experience in these methods broadens, and improvements are made, it is probable that operations will be extended to deeper sands, and that oil may be recovered by mining in all fields where there is a considerable thickness of oil-saturated sand. This may be true even of the California fields where the sands lie at depths down to 5,000 feet since the great thickness of sand and the large amount of oil might more than offset the increased expense, permitting the recovery of oil

at a price comparable to the cost of mining in shallow fields.

The present status of the known improved methods of oil recovery indicates that these methods should not be applied until flowing and pumping have ceased.

In flooding, all the oil recovered is apparently flushed out by the water. There is reason to believe that water admitted to a sand in the early life of the field would entrap more oil than it would if it were admitted at a later stage of development after flowing and pumping had removed as much oil as possible. The amount left in the sand would be less if the sand had been drained as thoroughly as possible before flooding.

It is the opinion of several operators and geologists that gas or air under pressure should be admitted to an oil sand at the time the wells stop flowing. At this stage of development the oil is still in a state of motion and is buoyant and volatile. It has been proven by experiment, however, that gas or air admitted into an oil sand under pressure will go into solution in the oil. By this means the buoyancy can be restored at any time, and the oil in the sand after complete exhaustion by pumping can be recovered as readily as it could have been immediately after flowing ceased.

In view of the difficulty of mining in the presence of gas, this operation should be deferred until flowing and pumping have exhausted the gas as completely as possible.

REPORT ON SUPPLY OF PETROLEUM IN THE
UNITED STATES

SECTION 2. OIL SHALE, COAL AND LIGNITE

ESTIMATED LIQUID PRODUCTS FROM OIL SHALE, COAL AND LIGNITE

The information on which the estimates are based has been gathered from available sources; including surveys by government and state departments, universities, consulting geologists, private information of various companies, and the results of research carried on by many individuals.

As a result of carefully going over all available information from all sources, the estimates given below have been formed, taking the conservative viewpoint in all cases. The estimated quantities refer only to materials within the United States.

Time of Substitutes Use.—If and when the cost of recovery of oil and gasoline from shale, coal and lignite will permit this oil and gasoline to be sold in competition with similar products from present and other sources of supply, then, and then only, will these products be commercially available.

Oil Shale.—The total amount of oil shale is about three hundred and ninety-four billion (394,000,000,000) short tons from which can be recovered about one hundred and eight billion (108,000,000,000) barrels (42 gallons) of crude shale oil. From this crude shale oil, about twenty-five billion (25,000,000,000) barrels of motor fuels, including average straight run and cracked products, can be obtained.

Coal.—The estimates of the coal in the ground are based on the conclusions of the International Geological Congress at Ottawa in 1913, corrected to 1924. The quantity of coal within 3,000 feet of the surface is about two trillion, four hundred and sixty billion (2,460,000,000,000) tons, while if coal to 6,000 feet is worked, there would be about three trillion, one hundred billion (3,100,000,000,000) tons.

The maximum amount of liquid products is estimated at

about two trillion (2,000,000,000,000) barrels (42 gallons). However, taking everything into account, the possible commercial recovery from the coal suited to that purpose would be about five hundred and twenty-five billion (525,000,000,000) barrels (42 gallons).

The estimated commercial yield of motor fuel from the above liquid products shows about ninety-two billion (92,000,000,000) barrels.

Lignites.—The quantity of lignites available is estimated at about nine hundred and eighty-six billion (986,000,000,000) tons. From this about seventy billion (70,000,000,000) barrels (42 gallons) of liquid products would be obtained and of this, about twelve billion (12,000,000,000) barrels could be used as motor fuel.

Lubricating Oils.—There is reason to suppose that satisfactory lubricating oils will be obtained from shale oil. Regarding lubricating oils from coal and lignite tars, it is not so promising but future developments will probably show improvement.

Summary.—The estimated quantities of oil shale, coal and lignite show a total tonnage available of about four trillion (4,000,000,000,000) tons.

The total liquid products available are about seven hundred billion (700,000,000,000) barrels of 42 gallons, considering only commercially feasible recoverable products.

The total motor fuel from the above will probably be about one hundred and thirty-nine billion (139,000,000,000) barrels of 42 gallons.

CONDENSED REPORT ON PRODUCTS FROM OIL SHALE, COAL AND LIGNITE

OIL SHALE

Estimates are made from data available from such sources as the U. S. Bureau of Mines, U. S. Geological Survey, various state bureaus of mines, state university geologists, consulting geologists, and private information.

The States known to have oil shale in commercial quantities are eight, as follows:

- | | |
|---------------|------------|
| 1. California | 5. Montana |
| 2. Colorado | 6. Nevada |
| 3. Indiana | 7. Utah |
| 4. Kentucky | 8. Wyoming |

The estimated quantities of oil shale and shale oil that may be recovered are given by states in the following table:

State	Oil Shale in 1,000 Tons (Short)	Shale Oil in 1,000 Bbls. (42 Gal.)
1. California.....	13,939,200	5,575,680
2. Colorado.....	113,792,000	40,640,000
3. Indiana.....	69,696,000	13,939,200
4. Kentucky.....	90,604,800	28,993,536
5. Montana.....	6,969,600	1,393,920
6. Nevada.....	7,219	2,165
7. Utah.....	92,159,000	16,588,620
8. Wyoming.....	7,176,000	1,291,680
Total.....	394,343,819	108,424,801

The above résumé shows that we have in reserve in the United States an estimated quantity of

Oil Shale (short tons).....	394,343,819,000
Shale Oil (42 gal. bbls.).....	108,424,801,000

It is estimated that about 20% of motor fuel may be obtained from shale oil by natural distillation. If shale

oil is cracked there may be a possibility of obtaining 30% motor fuel. Averaging up the two above figures, it is estimated that about twenty-five billion (25,000,000,000) barrels of motor fuel may be obtained from the above shale oil.

COAL

Estimates of the coal in the ground are based on the conclusions of the International Geological Congress in Ottawa in 1913. The estimates are given on two bases showing:

(A) The maximum possible total recoverable.

(B) The best reasonably possible average commercial recovery.

Coal Reserves.—The amount of coal reserves is as follows:

	In Thousands of Tons	
	To 3000 Ft.	To 6000 Ft.
Semi-bituminous.....	45,660,000	45,660,000
Bituminous.....	1,428,700,000	1,650,900,000
Sub-bituminous.....	986,900,000	1,431,300,000
Total.....	2,461,260,000	3,127,860,000

Possible Total Liquid Products.—The estimate of the amount of total liquid products which may be obtained from the coal listed above is as follows:

	In Thousands of 42-Gal. Barrels	
	Estimated Maximum	Estimated Commercial
Semi-bituminous.....	17,400,000	9,760,000
Bituminous.....	1,260,000,000	304,400,000
Sub-bituminous.....	818,000,000	211,400,000
Total.....	2,095,400,000	525,560,000

Possible Light Motor Fuel.—From the above total liquid products it is estimated that the following light motor fuel may be obtained:

	In Thousands of 42-Gal. Barrels	
	Estimated Maximum	Estimated Commercial
Semi-bituminous.....	4,340,000	1,710,000
Bituminous.....	252,000,000	53,300,000
Sub-bituminous.....	136,300,000	37,000,000
Total.....	392,640,000	92,010,000

NOTES.—No lignite or anthracite coal products are included. The results on lignite are given below under Lignites. No commercial liquid products are obtainable from anthracite.

The above estimates take the total tonnage and assume for example that only 60 per cent of the coal to the 3000 ft. level will be lifted and of the amount lifted three-quarters will be processed for liquid products. The average of 20 gals. of tar per ton was used in estimating.

The possible light fuel is estimated at 3.5 gals. per ton. Although the average yield today is only about 2.5 gals. per ton it is believed that by the time coal is carbonized for liquid products, methods of distillation will be provided so that an increased yield of light motor fuel equivalent to about 3.5 gals. per ton will be obtained.

LIGNITES

The quantity estimates and classification of lignite are taken from the report of the Twelfth Geological Congress, Ottawa, Canada, 1913, entitled, "Coal Resources of the World," and are as follows:

Possible Lignite Resources.

	In Thousands of Tons
Gulf Province.....	21,000,000
North Great Plains Province.....	965,000,000
Total.....	986,000,000

NOTES.—The "Gulf Province" includes Texas and Arkansas.

The "North Great Plains Province" includes North Dakota, South Dakota, Montana, Wyoming, Colorado and New Mexico.

Estimated Liquid Products.

	In Thousands of 42-Gal. Barrels
Total tar, all United States.....	70,500,000
Possible motor fuel.....	11,700,000

The average tar per ton is estimated at 3.0 gallons and the average motor fuel at 0.5 gallon.

RÉSUMÉ

Collecting all the above facts together, we have the following estimate of possible products:

	In Thousands of Tons	Oil or Tar Recoverable in Thousands of 42-Gal. Barrels
Oil shale.....	394,343,819	108,424,801
Coal.....	2,461,260,000*	2,095,400,000†
Coal.....	3,127,860,000‡	525,560,000§
Lignite.....	986,000,000	70,500,000

* Coal to 3000 ft. level (estimated).

† Coal to 6000 ft. level (estimated).

‡ Coal tar recoverable, estimated maximum.

§ Coal tar recoverable, estimated commercial.

OIL SHALE RESOURCES OF THE UNITED STATES

Classification of Raw Materials.—There are in the United States several types of rock which do not contain free oil but which will yield oil when heated or in other words will yield oil when subjected to pyrolysis. These oil-yielding materials may be listed in order of importance as follows:

1. Laminated shale of the Green River formation in Colorado, Utah, Wyoming and Nevada.
2. Cannel Coal, Canneloid lignite and Canneloid shales.
3. Black shales of the Devonian and Carboniferous formations of the eastern part of the United States.
4. Black phosphatic shales of the Rocky Mountain region.

5. Dark shales of Cretaceous and other formations.

Of these, the shales of the Green River formation are by far the richest and most extensive and therefore of the most immediate interest:

In northeastern Utah and northwestern Colorado the Green River formation occupies the interior of the great Uinta Basin, along the south and east rim of which are beds of oil shale thick enough to mine and rich enough to warrant the establishment of an industry of immense proportions and it has been stated (*a*) that along the outcrop of the oil shale beds in Colorado and Utah there are but few places where there is not a bed of oil shale more than 10 feet thick, which is capable of yielding at least a barrel of oil to the ton of shale and in some places, particularly near Grand Valley and DeBeque, Colorado, and Watson, Utah, there is an aggregate thickness of rich shale of 100 feet or more. Locally, beds of oil shale too thin to warrant mining, have been found which will yield as much as two barrels of oil per ton. Based upon the investigation of the Geological Survey, the government has in this area classified nearly 4,000,000 acres valuable for their oil shale. The greatest thickness of oil shale is to be found in that part of the basin between Rifle, Colorado, on the east and Watson, Utah, on the west, where there are beds of rich shale aggregating more than 100 feet in thickness, much of which shale is capable of yielding a barrel (42 gallons) or more of oil per ton. (Winchester. Railroad Red Book, January, 1919, page 22.)

Oil shales are known to occur and have been described in 18 states of the United States as follows:

Eastern United States—Indiana, Illinois, Kentucky, Maryland, Ohio, Pennsylvania, Tennessee, West Virginia.

Western United States.—Arkansas, California, Colorado, Idaho, Montana, Missouri, Oklahoma, Nevada, Utah, Wyoming.

By far the most important occurrences from the standpoints of quantity, quality and facility of mining are in Colorado, Utah and Wyoming. In Colorado these oil shales occupy an area of about 1,900 square miles, chiefly in Rio Blanco and Garfield Counties lying between White River on the north and Grand River on the south. In Utah the area occupied is perhaps three times as large as that in Colorado and lies mainly in the Uinta Basin in Uinta, Carbon Du-

chesne, Wasatch and Utah Counties. In Wyoming an area of more than 2,800 square miles in Sweetwater and Uinta Counties of the Green River basin is occupied by similar shales. *In these three states, the oil shales are known to occupy an area of 10,000 square miles.*

The maximum thickness of the Green River formation (as given by Winchester, U. S. Geol. Survey Bul. 641-F, page 165) is 2,600 feet of which 1,550 feet are oil yielding. Utah gives a total thickness of 1,047 feet, of which there is a total of 61 feet of oil shale and 57 feet in beds more than 1 foot thick which will yield 15 gallons or more of oil to the ton. (U.S. Geol. Survey Bull. 641-F and 691-B).

Oil Content.—The oil content of the shale varies with different beds in the same location, and also in different places along the outcrop from a minimum of about 1 gallon per ton to a maximum of 90 gallons per ton. Samples (194) analyzed by the United States Geological Survey (Bul. No. 641-F and 691-B) gave the following results:

Less than 10 gals. per ton.....	42 samples
10-20 gals. per ton.....	71 samples
20-30 gals. per ton.....	42 samples
30-40 gals. per ton.....	21 samples
Above 40 gals. per ton.....	18 samples

About two-thirds of the samples analyzed yielded 10 to 40 gallons per ton.

Average Oil Content from Shale.—The following figures are based on the results of one hundred and thirty-two analyses published by the United States Geological Survey, forty-two analyses made in the laboratories of the Colorado School of Mines, and thirty-one analyses from other sources. Fifty-four of the analyses are on Colorado shales, fifty-two on Utah shales, forty-five on Wyoming shales and fifty-four on Nevada shales.

It is estimated by the U. S. Geological Survey that Colorado has enough shale, in beds three feet or more thick, capable of yielding an average of more than 25 gallons per ton to produce about twenty billion (20,000,000,000) barrels of crude

Number of Analyses	Constituent	Unit	Minimum	Average	Maximum
205	Shale oil	Gal. per T.	0.3	38.00	90.0
205	Shale oil	Spec. grav.	0.832	0.890	0.950
163	Ammonium sulfate	Lb. per T.	0.40	9.40	20.0
64	Gas	Cu. ft. per T.	400.00	3800.00	5600.00
26	Water	Gals. per T.	2.00	4.8	8.50
26	Spent shale	Lb. per T.	900.00	1200.00	1800.00
26	Sulfur	Per cent	0.25	0.80	5.20
16	Heating value	B.T.U.	1000.00	4500.00	8000.00
6	Carbon	Per cent	0.83	22.50	37.5

oil, from which two billion (2,000,000,000) barrels of gasoline may be extracted, and about 300,000,000 tons of ammonium sulfate. Utah is credited with sufficient shale to produce forty-two billion, eight hundred million (42,800,000,000) barrels of crude shale oil and about 500,000,000 tons of ammonium sulfate, while in Wyoming the oil shale covers an area nearly one-third larger than in Colorado.

The estimated reserves in the oil shales of Colorado, Utah, Wyoming and Nevada, in beds 3 feet or more thick and capable of yielding 25 gallons or more per ton, seventy-five billion (75,000,000,000) barrels.

In other words, the estimated oil reserves in the oil shale of these four states is sixty-three billion, six hundred sixty-two million (63,662,000,000) barrels more than the oil that has already been extracted plus that estimated as remaining in the ground in the United States. These estimates are scientific guesses based on a consideration of all available data.

Estimated Oil, per Acre.—Two thousand one hundred and seventy-eight tons of shale will cover an acre of ground one foot thick, and it is estimated that there are three and one-half million acres of shale in Utah, Wyoming and Colorado. Shales covering this area are placed at 2,000 feet thick and the Green River deposit is of equal

thickness, totaling 4,000 feet in all. With 2,178 tons per acre, the estimated oil content per acre is placed at 2,178 barrels to the acre. (W. J. Martine, Mt. State Mineral Age, 9, No. 7, 1924.)

In a recent article on Oil Shale (Chem. and Met. Eng., Vol. 31, No. 16, 1924), S. D. Kirkpatrick gave the following estimate of oil shale reserves based largely on the U. S. Geological Survey Reports.

The total area of oil shale land in Colorado is approximately 896,000 acres; in Utah, 2,700,000 acres, and in Wyoming, 500,000 acres. Conservative estimates based on known depths of average workable shale indicate yields of 75,000 barrels per acre for Colorado; 15,000 barrels for Utah and 6,000 barrels for Wyoming. These figures give the remarkable totals of sixty-seven billion, two hundred million (67,200,000,000) barrels for the Colorado reserve, forty billion, five hundred million (40,500,000,000) barrels for Utah and three billion (3,000,000,000) for Wyoming or in all, one hundred ten billion, seven hundred million (110,700,000,000) barrels. It is easier to comprehend this gigantic quantity if we compare it with petroleum production. From the time the first well was drilled in 1859 to the end of August, 1924, this country has produced *seven billion, six hundred sixty-six million seven hundred seventy-two thousand (7,666,772,000) barrels.* In other words, *our oil shale reserves in the three states of Colorado, Utah and Wyoming contain fourteen times as much oil as has been taken from the ground in the entire history of the American petroleum industry.* Certainly these reserves are ample to supply any reasonable demand for at least a century.

Area in Naval Shale Reserves.—Reserve No. 1, Western Colorado, 45,444 acres. Reserve No. 2, Utah, 86,584 acres. The Naval Reserve constitutes only about 3% of the total area of estimated shale land.

D. E. Winchester (U.S. Geol. Survey Bulletin No. 729) estimates the quantity of shale oil recoverable from the oil shales of Colorado, Utah and Wyoming to be as follows:

	Barrels
Colorado.....	40,640,000,000
Utah (based on 40% recovery).....	13,166,000,000
Wyoming.....	1,537,000,000
Total.....	55,343,000,000

The Naval Oil Reserves were created in 1916 and from incomplete information it was estimated that each reserve was capable of producing somewhere near 500,000,000 barrels of oil. Subsequent studies by the U. S. Geological Survey and property owners in the immediate vicinity have proven that the Colorado reserve alone is capable of producing upwards of two billion five hundred million (2,500,000,000) barrels of oil (five times the original estimate).

ESTIMATION OF OIL SHALE RESERVES BY STATES

Oil Shales of Nevada.—The oil shales of Nevada are mostly in the eastern district near Elko and Carlin. The Nevada shales generally lie in somewhat shallow basins of considerable extent. As a rule the beds are rather thin, dip steeply and are extensively fielded and faulted.

The richest seams of oil are about 4 feet thick and yield 30–35 gallons of oil per ton. The beds dip at an angle from 20–25°, making mining conditions less favorable than found in some of the deposits in Colorado and Utah. A complete survey of the Nevada shale oil deposits has not been made available so an estimate of the possible yield of oil cannot be made. The deposit covers an area of about 30 square miles.

Winchester (U.S. Geol. Survey Bull. No. 729, page 97, 1923) has estimated that the Elko District in Nevada, “would yield about 7,219,000 short tons of shale which will yield more than 15 gallons of oil to the ton when distilled.” At the rate of 15 barrels per ton this area would yield 2,165,700 barrels of shale oil. A plant has been operating in this district over a period of three years, and has been obtaining an average yield of 30 gallons per ton.

Utah Oil Shales.—J. B. Jensen (Shale Review, Vol. 4, May, 1922, page 4), states that oil shales of Utah carry twenty billion (20,000,000,000) barrels of oil.

Winchester (loc. cit.) reports that

The Utah shale deposits contain at least ninety-two billion, one

hundred fifty-nine million (92,159,000,000) tons of shale which will yield as much as 15 gallons of oil to the ton when distilled. In commercial practice it may be possible to recover 60 per cent of this tonnage, although, because of the several unknown factors involved, it may be safe to suggest that perhaps 40% may be recovered.

Assuming a recovery of 60% this amount of shale would yield sixteen billion, five hundred eighty-eight million, six hundred twenty thousand (16,588,620,000) barrels of crude shale oil.

Oil Shales of Wyoming.—Winchester (loc. cit) reports on the shale deposits as follows:

Although the data available indicate that the oil shale in southwestern Wyoming is in thin beds and that rich shale underlies a comparatively small area, the knowledge of the part of the region north of the Union Pacific Railroad and of the Southern Red Desert Basin is so meager that any estimate of the amount of shale in Wyoming is very hazardous. However, it is thought that the total quantity is not less than seven billion, one hundred seventy-six million (7,176,000,000) short tons of shale that will yield at least 15 gallons to the ton. Perhaps not more than 60 per cent of this total would be recovered, even under the most ideal mining conditions.

An average yield of 15 gallons per ton with a 60% recovery would produce one billion, two hundred ninety-one million, six hundred eighty thousand (1,291,680,000) barrels of crude shale oil.

Colorado Oil Shales.—D. E. Winchester (U. S. Geol. Survey Bull. No. 729, 1923) gives the following estimate for the Shale Oil reserves in the state of Colorado:

After a careful study of the thickness and oil-yielding capacity of the shales exposed in each of the localities where sections have been measured, it is estimated that if 60% of the total shale in northwestern Colorado existing in the ground as beds three feet or more thick and yielding at least 15 gallons of oil to the ton were treated in retorts it would produce a total of forty billion six hundred forty million (40,640,000,000) barrels (42 gallons each) of crude shale oil. If 60% of the nitrogen in the shale that is treated is converted into ammonium sulfate, the yield of this substance should approximate 400,000,000 tons.

V. C. Alderson in his book "The Oil Shale Industry," (p. 31, 1920) makes the following calculations for the amount of oil shale available in the state of Colorado:

An acre contains 43,560 square feet. A seam of oil shale 10 feet thick would contain 435,600 cubic feet. Eighteen cubic feet of shale weighs one ton. Hence there are 24,200 tons of shale in one acre of a seam 10 feet thick. In a square mile there are 640 acres and therefore, 15,488,000 tons of shale. There are 2,500 square miles of shale in Colorado, or thirty-eight billion, seven hundred twenty million (38,720,000,000) tons. Assume that only one-half is available and there remains nineteen billion, three hundred sixty million (19,360,000,000) tons of available shale. These are figures for one 10-foot seam only. A conservative estimate is 30 feet of workable shale or a total of fifty-eight billion, eighty million (58,080,000,000) tons of available shale. A fair average production is a barrel of oil to the ton of shale or fifty-eight billion, eighty million (58,080,000,000) barrels of oil available. If 100 plants were in operation, each treating 2,000 tons daily, they would have a daily production of 200,000 barrels. To treat this amount would require 290,400 days or 800 years, approximately.

Records of the Glenwood, Colorado, Land Office, show that up to the end of 1922, 25,091.82 acres of oil land in Colorado had been patented; that final receiver's certificates had been issued on 15,887 acres and that applications were pending on 6,850 acres.

Delos D. Potter, an engineer of Denver, Colorado, has estimated that in Colorado alone we have 900,000 acres of oil shale land, with an oil content in beds of workable thickness amounting to sixty-seven billion (67,000,000,000) barrels, or an average of 75,000 barrels per acre.

U. S. Senator Lawrence C. Phipps, of Denver, Colorado, gave out the following data in an address before the American Mining Congress at Milwaukee, Wisconsin, September 24-29, 1923. The area of these shale oil lands in Colorado alone amounts in round figures to 900,000 acres, while that of

Utah is approximately three times as extensive, although the quality of shale is not so rich and will perhaps yield only about one-fifth of the quantity of oil per acre that may be counted upon from the Colorado fields. The state of Wyoming also has about half a million acres of oil shale lands, but so far as present investigation has determined, the yield of oil per acre will average only 6,000 barrels, as against 15,000 barrels per acre for the Utah lands, and 75,000 barrels per acre for those in Colorado.

Taking this rate of production for Colorado alone, we have a reserve of about sixty-seven billion, five hundred million (67,500,000,000) barrels of oil; for Utah, forty billion, five hundred million (40,500,000,000) barrels; and for Wyoming, three billion (3,000,000,000) barrels. While the figure for Colorado production may appear optimistic, attention is called to the fact that careful sampling of twelve beds of workable thickness in the Parachute Canyon district indicated a yield of 185,000 barrels per acre as against the estimate of 75,000 barrels, which has been used in the above figures for Colorado reserves.

These figures should be contrasted with the estimate made about one year ago by the U. S. Geological Survey on the reserve of petroleum underground, recoverable by current production methods, which was given as nine billion, one hundred fifty million (9,150,000,000) barrels.

Oil Shales of California.—The California deposits are not true oil shales but are inspissated products from which oil can be extracted by suitable solvents. The mineral matter of the shale is diatomaceous and the beds that yield oil occur in massive formation. These shales occur with little or no overburden and most of it can be mined by surface workings.

The average yield is about 20 gallons per ton. The oil is an asphalt base product containing a high per cent of sulfur and nitrogen. The deposit is local and the exact area or an estimate of their oil content could not be obtained, except from one source (see page 136).

Oil Shales from Kentucky and Indiana.—Samples of oil shale from Kentucky and Indiana were retorted in a laboratory apparatus to determine the yields of oil and other constituents.

The results on one sample from each state are shown below. The column marked "W-1" refers to a sample of oil shale received from a "slate quarry" near Scottsburg, Indiana. At present this material is quarried for the purpose of furnishing road surfacing material. The deposit of shale itself was somewhat weathered. Over great areas between Scottsburg and New Albany and to the South, oil shale is practically on the surface, there being only two to six feet of soil over it. This shale is not supposed to be very rich.

The sample marked "W-2" is a Kentucky shale taken about one mile west of Clay City, Kentucky, and across the river. The sample was taken from the basal beds of the shale series and from a 100-foot thick stratum.

Yields of Products per Ton	W-1	W-2
Crude shale oil (dry), gallons.....	8.9	9.2
Water, gallons.....	9.9	6.6
Spent shale, per cent.....	85.8	75.0
Gas, cubic feet, corrected.....	577	412
Ammonium sulfate, pounds.....	5.4	2.0

Black shales capable of yielding possibly economic quantities of oil, occur in the states of Indiana, Illinois, Kentucky, Ohio, New York, Pennsylvania, West Virginia and Tennessee. The average yield of oil from these shales is low in comparison with that of the shales of the Rocky Mountain region. However, the thickness and the extent of the Eastern deposits and the fact that they may be mined by easy and inexpensive methods make their development in many places seem almost as feasible as that of many of the Western deposits.

The New Albany shale district of Indiana covers an area of about 500 square miles with an average depth of about 50 feet. This type of shale will give an average yield of about 10 gallons of crude oil per ton of shale retorted. This shale has an advantage in the fact that it occurs very near the surface with little or no over burden.

The Kentucky shale deposits cover a rather narrow strip through the state and cover an area of about 1,000 square miles. On the basis of an area of 1,000 square miles, 50-foot thickness and 130 pounds to the cubic foot, there are available, therefore, ninety billion, six hundred four million, eight hundred thousand (90,604,800,000) tons of shale. (C. S. Crouse, Univ. of Kentucky). The shale gives an average yield of about 16 gallons per ton. This would be an estimated yield of twenty-eight billion, nine hundred ninety-three million, five hundred thirty-six thousand (28,993,536,000) fifty-gallon barrels of shale oil. The overburden is very thin and in places lacking.

The yields of liquid hydrocarbons from Kentucky and Indiana shales are not as high as those from the Western deposits. However, the Eastern deposits have a marked advantage for commercial utilization because they are close to transportation, have little or no overburden, plenty of water available and close to a ready market for finished products.

The oil shale deposits of Indiana have been carefully studied by John R. Reeves of the Indiana University. They form a northerly extension of the Kentucky deposit. Reeves estimates that 45,000,000 tons can be easily recovered from surface workings with still more that can be mined by underground conditions.

State	Approximate Tons of Shale Available	Area in Square Miles	Type of Oil	Gallons per Ton	Recov- ery, Per Ct.	Available Barrels (42 Gals.)
Colorado *	113,792,000,000	.....	Mixed base	15	60	40,640,000,000
Utah *	92,159,000,000	.....	Mixed base	15	60	16,588,620,000
Wyoming *	7,176,000,000	.....	Mixed base	15	60	1,291,680,000
Nevada *	7,219,000	30	Paraf- fine base	15	60	2,165,000
California †	13,939,200,000	100-1000 ft. thick	As- phaltic	20	100	5,575,680,000
Kentucky ‡	90,604,800,000	1000	Mixed base	16	100	28,993,536,000
Indiana §	69,696,000,000	500-100 ft. thick	Mixed base	10	100	13,939,200,000
Montana *	6,969,600,000	500-10	.....	10	100	1,393,920,000
Total...	.....	.....	.....	.....	.....	108,424,801,000

* U. S. Geol. Survey Estimate. Bulletins Nos. 641-F and 691-B.

† Calculated from figures by D. T. Day, Handbook Petroleum Industry, Vol. 1, p. 836.

‡ S. C. Crouse, Univ. of Kentucky, Colo. School Mines Quart., Oct., 1922.

§ J. R. Reeves, Indiana University, Bur. of Mines Report, No. 2466.

CALIFORNIA

Location	Thickness Sampled, Feet	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
Santa Barbara County:					
Casmalia	27	25.5	19.7	1500	
Casmalia	11	23.8	21.0	1300	
Casmalia	31	25.8	21.5	1300	
Casmalia	55	27.4	22.0	1400	
Graciosa Ridge.....	.....	52	21.5		
Casmalia .....	.....	55	.....	1425	
Sisquoc Ranch *.....	45	36	25.0	1700	
Carpinteria *	14	42	23.6	1650	
Kern County:					
McKittrick.....	.....	62			
Riverside County:					
Elsinore.....	5	65	36.0		

* Saturated sands.

REMARKS:

Counties: Santa Barbara, Ventura, Los Angeles, Kern and San Bernardino.

Age: Miocene. Formation, Monterey.

Area in State: 100 to 150 sq. miles.

Thickness of Formation: 100-5000 ft.

Analyses and samples by Geo. W. Turner, David E. Day, and D. T. Day.

Typical California shale is a porous diatomaceous shale more or less saturated with petroleum. Deposits are generally related to producing fields and are found near the crests of large anticlines. The Elsinore deposit is an exception to this rule, the shale being quite similar to that from Elko, Nevada.

MONTANA

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Phosphate, Per Cent
Daly spur O.S.L.R.R. Sec. 2, T.9S., R.10W.	Ft. In. 4 8	14	.....	.....	3.26
Daly spur O.S.L.R.R. Sec. 2, T.9S., R.10W.	4 7	0	.....	.....	19.41
Daly spur O.S.L.R.R. Sec. 2, T.9S., R.10W.	14 0	17	.....	.....	1.72
Daly spur O.S.L.R.R. Sec. 2, T.9S., R.10W.	10 0	13	.....	.....	
Small Horn Canyon, Sec. 14, T.9S., R.9W.	5 6	21	.....	.....	0.63
Small Horn Canyon, Sec. 14, T.9S., R.9W.	17 8	17			
Dry Canyon near Dell, Sec. 12, T.13S., R.10W.	8 0	17	.....	.....	5.94
Little Sheep Creek, Sec. 4, T.15S., R.9W.	14 0	16	.....	.....	5.57
Little Sheep Creek, Sec. 4, T.15S., R.9W.	4 0	12	.....	.....	10.28
Little Sheep Creek, Sec. 4, T.15S., R.9W.	2 6	12	.....	.....	10.28

REMARKS:

Counties: Beaverhead.

Age: Permian. Formation, Phosphoria. Steep dip, faults.

Area in State: 500 sq. miles.

General Averages: U. S. G. S. samples of Montana shale:

Samples examined: 15.

Average oil content: 12.25 U. S. gallons per short ton.

Average yield of phosphoric acid in oil bearing beds: 4%.

Average yield of phosphoric acid in related beds: 15.77%.

Percentage of samples which were average or over: 60%.

Average thickness of beds represented by these samples: 10 ft. 3 in.

Average oil content of these commercial beds: 16 gals. per ton.

COLORADO

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
Conn Creek, Sec. 1, T.7S., R.98W.....	Ft. In. 1 4	61-68	17-24	.....	22.5 (1)
Kimball Creek, Sec. 5, T.7S., R.100W.....	6 0	26-31	20.5	.....	.... (1)
Parachute Creek, Sec. 29, T.5S., R.95W....	5 10	20	21	.....	.... (1)
Parachute Creek, Sec. 36, T.5S., R.96W....	6 4	18	27.1	.....	8.7 (2)
Roan Creek, Sec. 1, T.7S., R.98W.....	.....	65.3	23.6	4549	7.0 (2)
Book Cliffs, Sec. 6, T.6S., R.94W.....	10 0	40.6	29.2	1916	4.3 (2)
Book Cliffs, Sec. 22, T.6S., R.95W.....	8 0	20.7	33.1	.....	.... (2)
Dry Fork Creek, Sec. 7, T.7S., R.100W....	5 0	38	27.5	.....	7.4 (2)

REMARKS:

Counties: Garfield, Rio Blanco, Moffat and Mesa.

Age: Eocene. Formation, Green River.

Area in State: 2500 sq. miles.

General Averages: U. S. G. S. samples of Colorado shale:

Samples examined: 65.

Average oil content, 19.05 U. S. gallons per short ton.

Average gas yield: 2705 cu. ft. per short ton (20 samples).

Average yield ammonia sulfate: 7.3 lbs. per short ton (36 samples).

Percentage of samples examined which were average or above: 37%.

Average thickness of beds represented by these samples: 4 ft. 6 in.

Average oil content of these commercial beds: 29.8 U. S. gallons per ton.

UTAH

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
	Ft. In.				
Soldier's Summit.....	6 3	16.8	26.6	2864	3.5
Soldier's Summit (2 miles north).....	6 11	24	24.7	.....	12.21
Joab.....	2 9	11.9	25.6	1198	2.5
Watson, Sec. 27, T. 11S., R.25E.....	6 10	37	30.42	.....	7.8
Hell's Hole Canyon, Sec. 15, T.10S., R.25E.	4 8	45	26	.....	9.2
Dragon, Sec. 4, T.12S., R.25E.....	4 4	30	23.2	.....	7.0
Bitter Creek, 12 miles S.W. Dragon.....	5 9	43	27.1	.....	5.2
Willow Creek, 28 miles W. Dragon.....	5 2	15	28.4	.....	2.66
Soldier's Summit (6 miles north).....	12 6	19	28.5	.....	4.4
Colton (4 miles east)...	5 0	11	27.5	.....	3.6

REMARKS:

Counties: Carbon, Duchesne, Uinta and Utah.

Age: Eocene. Formation, Green River. Structure, Synclinal basin.

Area in State: 3500 sq. miles.

Analyses from U. S. G. S., Bull. 691-B; Dean E. Winchester

General Averages: U. S. G. S. samples of Utah shale:

Samples examined: 94.

Average oil content: 23.8 gals. per short ton.

Average gas yield: 2031 cu. ft. per ton.

Average yield ammonia sulfate: 4.9 lbs. per ton.

Percentage of samples examined which were average or above: 39%.

Average thickness of beds represented by these samples: 4 ft. 3 in.

Average oil content of these commercial beds: 36 gals. per ton.

WYOMING

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
Red Desert Basin, Sec. 9, T.13N., R.99N....	Ft. In. 5 0	30	30.79	.....	3.94
On Green River, Sec. 27, T.13N.R.108W...	3 3	19	.....	.....	9.32
On Green River, Sec. 36, T.16N., R.108W.	6 0	13	26.86	.....	5.06
S. of town of Green River, Sec.27, T.16N., R.106W.....	8 1	19	25.50	.....	8.68
At town of Green River, Sec.8, T.18N, R.107W	1 8	29	22.47	.....	11.71
Fossil Buttes, Sec. 5, T.21N., R.107W....	2 0	50	27.49	.....	2.0
* Green River, Sec. 25, T.17N., R.107W....	35 0	28	.....	1200	13.8
* Green River, Sec. 25, same Twp.....	26 0	34	.....	1200	16.2
* Sec. 27, T. and R. as above.....	30 0	33	.....	1420	14.8
* Green River, Sec. 22, T.16N., R.107W....	3 0	75	.....	2600	29.9

REMARKS:

Counties: Lincoln, Uinta and Sweetwater.

Age: Eocene. Formation, Green River.

Area in State: 3000 to 7000 sq. miles.

General Averages: U. S. G. S. samples of Colorado shale:

Samples examined: 41. Analysis from U. S. G. S., Bull. 641.

Average oil content: 14.5 U. S. gallons per short ton.

Average gas yield: 1605 cu. ft. per ton.

Average yield ammonia sulfate: 6.2 lbs. per ton.

Percentage of samples examined which were average or above: 37%.

Average thickness of beds represented by these samples: 4 ft. 2 in.

Average oil content of these commercial beds: 24.0 gals. per ton.

General Averages, private samples of Wyoming shale: (samples marked by (*) taken and examined by Erb Wuensch for American Shale and Petro. Co.).

Samples examined: 15.

Average oil content: 36 U. S. gallons per short ton.

Average thickness of beds: 17 ft.

Average gas yield: 1350 cu. ft. per short ton.

Average ammonia sulfate yield, dry: 6.3 lbs. per short ton.

Average ammonia sulfate yield, with steam: 16 lbs. per ton.

NEVADA

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
	Ft. In.				
Elko, at Catlin plant...	5 0	50			
Elko, Nev. ....	.....	86.8	28	3891	6.0
Elko, Nev.	2 4	50.0	35.8		4.5-8.4
Elko, So. Pacific *....	1 0	80	30		
Elko, So. Pacific †....	6 0	30	28		
Elko, So. Pacific ‡....	4 0	30	25		
Elko, So. Pacific.	12 0	15	28		
Elko, near Catlin.	7 0	35			
Elko, Berner Basin.	8 0	20	35		
North of Elko.	10 0	30	30		

REMARKS:

County: Elko.

* Determination by David T. Day

† Determination by Day and Winchester, U. S. G. S., Bull. 641.

‡ Determination by Dean E. Winchester, U. S. G. S., Bull. 641.

The Catlin Shale Products Co., Elko, Nevada, has been operating a 100-ton per day unit over a period of three years and their average yield has been about 30 gals. per ton.

KENTUCKY

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
	Ft.				
Louisville.....	8	11.2	.....	1016	
Crittenden Co.....		14.0	.....		2.58
Estell Co.....		23.30	.....		40.2
Powell Co.....		22.7	.....	4167	97.8
Rockcastle Co.....		8.0	.....	3000	
Taylor Co.....		27.75			
Fleming Co.....		21.5			
Breckenridge *		13.0			
Garrard.....		21.0			

* Cannel coal by G. H. Ashley, U. S. G. S., Bull. 659.

REMARKS:

Counties: Crittenden, Louisville, Caseyville, Clay City.

Age: Devonian. Formation, Chattanooga shale.

G. H. Ashley, U. S. G. S., Bull. 641.

Average from above analyses: 18.05 gals. per ton.

Average for samples retorted by Crouse, Univ. of Kentucky, 20.7 gals. per ton.

Average for samples retorted by Development Dept.: 9.0 gals. per ton.

INDIANA

Location	Thickness Sampled	Oil, Gallons per Ton	Gravity, Baumé	Gas, Cubic Feet per Ton	Ammonia Sulfate, Pounds per Ton
	Ft.				
New Albany.....		9.1		958	
New Albany.....		11.2		2043	0.15 (3)
New Albany.....		11.9		1197	0.0 (3)
Boonville.....		14.0		2522	0.97 (3)
Boonville.....		15.4		2922	0.61 (3)
Miscellaneous.....		10.0		997	28.5
Miscellaneous.....		12.75		912	22.2
Miscellaneous.....		18.00		1836	20.4
Miscellaneous.....		20.00			
Miscellaneous.....		30.00			

REMARKS:

Counties: Floyd, Clark, Scott, Jefferson, Jennings and Jackson.

Age: Devonian. Formation, New Albany.

Area in State: 500 sq. miles.

General Averages: U. S. G. S. and Indiana G. S. samples:

Samples examined: U. S. G. S., 8; Indiana G. S., 14.

Average oil content: U. S. G. S., 10.0 gals. per ton; I. G. S., 14.6 gals. per ton.

Average yield gas: U. S. G. S., 1400 cu. ft. per ton; I. G. S., 1076 cu. ft. per ton.

Average yield ammonia sulfate: I. G. S., 27.3 lbs. per ton.

Average thickness of formation: 70 to 140 ft.

YIELD OF DISTILLATION PRODUCTS FROM VARIOUS OIL SHALES

Kind of Shale	DeBeque, Colorado*	Scot- land*	Soldier Sum- mit, Utah*	Ken- tucky*	Elko, Nev.*	Cas- malia, Cal.†	In- diana‡
Oil yields, crude gal- lons per ton.....	35.73	16.4	49.5	15.0	59.1	24.0	10.0
Gravity, crude A. P. I.	23.5	28.8	24.3	17.8	28.0	21.0	19.0
Tops (into 275° C.), gallons per ton....	13.5	6.1	17.7	6.1	22.2	9.6	4.7
Per cent tops and scrubber naphtha..	37.8	40.0	39.6	40.9	40.9		
Tops and scrubber naphtha, gallons per ton.....	13.6	6.7	18.5	7.1	25.7		

Average yield of white products (into 275° C.) from above data, 11.4 gallons per ton.

YIELD OF PRODUCTS—SCOTTISH SHALE OIL †

FOR THE MAXIMUM PRODUCTION OF FUEL OIL

	Yield, Per Cent	Yield, Per Cent
Naphtha.....	9	10
Burning oil.....	.....	16
Wax.....	9	9
Fuel Oil.....	71	54
Total.....	89	89

* Bureau of Mines Report, No. 2603, May, 1924.

† Retorted by author.

‡ Bureau of Mines Bulletin, No. 210.

YIELD OF REFINED PRODUCTS FROM SCOTTISH SHALE OIL

Product	Yield, Per Cent
Naphtha (end point 450° F.).....	9.9
Illuminating and burning oil.....	24.8
Gas and fuel oil.....	24.4
Lubricating oil.....	6.6
Paraffin wax.....	9.5
Still coke.....	2.0
Loss, tars and gases.....	22.8
Total.....	100.0

Yield of White Products.—Figures in the table above are from actual analyses and it will be noted that the yields per ton are larger than those given on page 127. Using the lower yields in gallons per ton as given on page 127 and assuming the yield of naphtha (into 275° C.) as 40% on crude, the available yield of naphtha would be forty-three billion, three hundred sixty-nine million, nine hundred twenty thousand, four hundred (43,369,920,400) barrels.

Summary.—The above report shows an estimate of the oil shale resources in eight states known to have commercial deposits. The states with such deposits are Colorado, Utah, Wyoming, Nevada, California, Montana, Kentucky and Indiana and would yield an estimated grand total of *one hundred eight billion, four hundred twenty-four million, eight hundred one thousand* (108,424,801,000), *barrels of crude.* (Estimate by states is given on page 121.)

The estimates are made from available data such as furnished by the U. S. Bureau of Mines, U. S. Geological Survey, various state bureaus of mines, geologists from state universities, consulting geologists, reports by private geologists and general experience in retorting oil shale from various states. The estimates given in the grand total for Colorado, Utah and Wyoming are those prepared by

Dean E. Winchester, formerly with the U. S. Geological Survey. The figures given as estimates for the other states were calculated from an average from all the information available. The values are based on 60% and 100% recoveries but in commercial practice and with underground mining the recovery would probably be nearer the former figure.

ESTIMATE OF THE POSSIBLE FUTURE PRODUCTION OF LIQUID FUELS FROM COAL IN THE UNITED STATES

(Based on Certain Assumptions)

BY HORACE C. PORTER

Introduction.—Any worth while estimate of future development in the industries, to show possible production of any commodity therefrom, must use as a basis well-defined assumptions, else it becomes merely a prophecy, unsupported except by the author's sense of the probabilities or his intuition.

Parallel maximum and minimum estimates,—an upper and a lower limit,—each with its set of basic assumptions, form a more reasonable method of looking into the future than the adoption of a single basis declared arbitrarily to be most probable.

The present report on future oil production from coal, therefore, incorporates, (1) a maximum and, (2) a reduced or reasonably possible estimate, both based on assumptions whose validity or degree of probability the author does not vouch for. The assumptions are made under necessity and are the best that appear to be available. The report is a glance into the unknown future,—admittedly a piece of guess-work,—but one based on careful study of past and present development in the field.

Liquid products, capable of direct combustion as a whole, in open burners, can be produced from coal in much greater quantity than the so-called motor fuels, of light character, suited to the present prevailing type of automobile engine. Accordingly the estimate following is divided into items of (a) liquid fuels, and (b) motor fuel (interpreted as above explained).

On pages 152–153 is to be found the tabular statement of estimated production.

Basic Assumptions.

(I) *For Maximum Estimate*

(1) Coal reserves, as estimated by competent geologic authorities, (Ref. 1) are taken, for this maximum estimate, as the coal in the ground, to a depth of 6,000 feet, in seams of not less than 14 inches thickness, of ash content not over 25%, the tonnage reduced by 20% to accord with an 80% figure for practical mining recovery (high, in respect to present average practice). Lignite (as so classified by the U. S. Geological Survey) is *not* included.

(2) Delay in development of coal processing due to economic and technical difficulties, is *not* taken into account; this maximum estimate being of the potential liquid fuel in the minable coal lying underground at the close of the year 1924.

(3) Yield of liquid fuel product per ton is taken, for this maximum estimate, at the high average figure of 40 gallons per ton (on bituminous coal)—assuming:

(a) For one-third of the total available coal, the use of pressure-hydrogenation processes (Ref. 4) converting 40–50% of the solid into liquid fuel, thus yielding 70–90 gallons net per ton;

(b) For one-third of the coal, the use of low-temperature carbonization processes (Ref. 5), yielding 25–35 gallons, net, of liquid fuel per ton;

(c) For the remainder of the coal, the use of high temperature carbonization, gasification in gas producers, etc., direct burning of grades unsuited to carbonization, yielding a general average of 6–9 gallons per ton.

(4) For motor fuel, an average yield on bituminous coal, is assumed, for this maximum estimate, of 8 gallons per ton, more than double the yield now practically available; this being taken on the basis of possible future development of hydrogenation and cracking processes to be applied to the primary oils and tars and to the coal itself. These processes may, by further development, be found practicable, to

apply not only to the formation of lower-boiling fractions, but also to the chemical saturation thereof so as to lessen wash-loss in purification.

(5) The industrial and commercial practicability of processing practically all of the coal mined, even as preliminary to power production and railroad and steamship use, is not here considered. It is assumed, for the purpose of this maximum estimate, that the exhaustion, threatened or realized, of the petroleum reserves, will create in time such a demand for substitute liquid fuels, from coal or shale, that the costs of processing to obtain these latter, need not be taken into account, and all coal capable of being processed will be so applied.

(6) The parallel estimates of (a) total liquid fuel, and (b) motor fuel, are not additive, but are to be taken independently, since, if maximum motor fuel yield is to be obtained, considerable reduction of the maximum total fuel oil yield is probable through use of cracking processes.

(II) *For Reduced, Reasonably Possible Estimate*

(1) The coal reserves, for the purpose of this estimate, are taken on the basis of those estimated by the U. S. Geological Survey as available within 3,000 feet of the surface, retaining the 14-inch minimum thickness of seam and 25% maximum content of ash. The mining recovery, however, is here set at a practical maximum of $66\frac{2}{3}\%$ as used by the U. S. Geological Survey, rather than 80% as taken in the foregoing maximum computation. A further reduction, bringing the net merchantable coal recovery to 60%, is made for bone and slate and other dross, and for coal necessarily used in mining.

Lignite, again, is omitted, also anthracite.

(2) For this estimate, taking account of conditions that limit the economic practicability of pretreating all of the coal mined, but still assuming a heavy demand for petroleum substitutes such that their cost is not a factor, the assump-

tion is made that processing of coal will be carried out only to a reasonably practical extent, say to 75% of all coal leaving the mines. This allows 25% for continued burning of raw coal in a few small isolated plants where simplicity is a large factor, to some degree on railroad locomotives and steamships, and in certain metallurgical and other processes where use of raw coal and powdered coal fires is an advantage.

(3) The yield of liquid fuel from coal, for the purpose of this conservative estimate, is placed at a general average of 20 gallons per ton. It is assumed that pressure-hydrogenation processes may be developed to some extent, but not large, being restricted by the factors of high cost of apparatus, limited raw material suitable for use, and inability to produce the variety of fuel products required for domestic and power-plant purposes.

Low temperature carbonization is assumed to be capable of practical development to a limited extent, applicable to a part at least of central station power production, domestic fuel production and, by perfected processes, to the production of some part of the metallurgical coke requirement. High temperature carbonization is assumed to be continued in increased measure for production of city gas and the higher grades of metallurgical coke.

While some processes now under development, notably the rotary kiln, strictly low temperature carbonization processes, (Ref. 5) yield from high volatile coals 25-30 gallons of total fuel oil per ton, a conservative estimate for all coals and for a partial use of processes making good lump coke for metallurgical purposes, would place the yield at 20 gallons. The lower tar yields from high temperature carbonization would perhaps be compensated by a limited application of pressure-hydrogenation processes, so that the average yield would remain approximately 20 gallons.

(4) The possible average yield of motor fuel is placed conservatively in this estimate at 3.5 gallons per ton. This is an increase of 30-40% over the average yield now obtain-

able from different grades of coal, either by high-temperature or low-temperature processes, and is likely to result from improvements in carbonizing methods, designed to increase light oil formation, and from methods to be developed for decreasing wash losses of chemically unsaturated material. While in high temperature carbonization, best present practice may yield from high volatile coals 3.0 to 3.2 gallons of washed and redistilled motor fuel the average yield would not exceed 2.5-2.6 gallons. Low temperature methods in experimental plants have in some cases yielded slightly more than this, but on an average basis do not exceed 3 gallons of purified product.

(5) A further exhaustion of the coal reserves, without processing for oil recovery, is assumed, for the purpose of this conservative estimate, to be likely to take place. It is set, arbitrarily, in order to have some definite figure, at an amount equivalent to twenty-five years' coal consumption continued at the present rate, and 60% of it taken from the relatively high grade coal of the Eastern Province.

CALCULATION OF PRODUCTION ESTIMATES

With these basic assumptions and by the methods outlined in the foregoing the estimates have been calculated, and are presented in the table on the two succeeding pages:

ESTIMATE OF COAL SUPPLY OF LIQUID FUEL (TOTAL) AND OF MOTOR FUEL
TO BE HAD FROM COAL

	Millions of Tons		
	Semi-bituminous	Bituminous	Sub-bituminous
Original tonnage (within 3000 ft. of surface), short tons. (Ref. 1):			
Eastern Province.....	48,637	503,011	
Interior Province.....	1,226	528,273	
Northern Great Plains.....		45,553	284,548
Rocky Mountain Province.....		354,640	713,283
Pacific Coast.....		11,439	53,459
Total, United States.....	49,863	1,442,916	987,514
Additional tonnage between 3000 and 6000 ft. depth. (Ref. 1):			
Total United States.....		222,200	444,400
Exhaustion, to end of 1924. (Ref. 2):			
Total, United States.....	4,200	14,200	600
Estimated supply within 3000 ft. of surface:			
Total, United States.....	45,660	1,428,700	986,900
Estimated supply within 6000 ft. of surface. (Ref. 1):			
Total, United States.....	45,660	1,650,900	1,431,300
	Millions of Tons and Millions of 42-Gal. Barrels		
80% on 6000 ft. coal supply.....	36,528	1,320,720	1,145,040
Higher estimate, liquid fuel production, at 40 gals. per ton on bituminous, 20 gals. on semi-bituminous, and 30 gals. on sub-bituminous, stated in millions of barrels of 42 gals.	17,400	1,260,000	818,000
Higher estimate, motor fuel, at 8 gals. per ton on bituminous and 5 gals. on other.....	4,340	252,000	136,300

Continued

	Millions of Tons and Millions of 42-Gal. Barrels		
	Semi- bituminous	Bitumin- ous	Sub- bituminous
60% on 3000 ft. coal supply. (Ref. 3) ..	27,400	852,000	592,000
75% on this, to be processed.....	19,200	639,000	444,000
Liquid fuel, lower estimate, at 20 gals. per ton.....	9,760	304,400	211,400
Motor fuel, lower estimate at $3\frac{1}{2}$ gals. per ton.....	1,710	53,300	37,000
Recapitulation	Millions of Barrels, 42 Gals.		
	Higher Estimate	Lower Estimate	
Possible Liquid Fuel (Total):			
From semi-bituminous coal.....	17,400	9,760	
From bituminous coal.....	1,260,000	304,400	
From sub-bituminous coal.....	818,000	211,400	
Total.....	2,095,400	525,560	
Possible Motor Fuel (light):			
From semi-bituminous coal.....	4,340	1,710	
From bituminous coal.....	252,000	53,300	
From sub-bituminous coal.....	136,300	37,000	
Total.....	392,640	92,010	

REFERENCES

(1) Professional Paper 100-A, U. S. Geological Survey, 1917, by M. R. Campbell, gives synopsis of coal reserve figures of the Report of a Committee of the Twelfth International Geological Congress, Ottawa, 1913, on Coal Fields of the World; especially a table of the United States reserves and available supply by districts and coal ranks.

Richard Redmayne, in an address on The Coal Reserve of the World, to the World Power Conference, London, 1924 (*Colliery Guardian*, Vol. 128, 1924, pages 128-9), corroborates these estimates in the main. Incidentally discussing oil fuel supply he states: "The future supply of oil will be more and more derived from the distillation of oil shales and coal, or alternately by the actual liquefaction of coal."

(2) Professional Paper 100-A, U. S. Geological Survey, gives the coal production, by districts, up to the end of 1914. Later coal reports of the U. S. Geological Survey extend the production figures to 1924. These figures are here increased to 150% to express exhaustion of the coal to conform to the U. S. Geological Survey's estimate of a $66\frac{2}{3}\%$ average mining recovery. Distribution between the different ranks of coal is made roughly in accordance with published reports of production of different ranks in certain years.

(3) To estimate the coal practically available in the future, conservatively, for pre-treatment and oil recovery, the original tonnage remaining at end of 1924 is further reduced by three billion (3,000,000,000) tons semi-bituminous, nine billion (9,000,000,000) tons bituminous, and 500,000,000 tons sub-bituminous, to cover exhaustion during twenty-five years while the coal-processing industry is gradually developing. The remainder is then reduced to 60% to obtain the practical mining and marketing recovery, as earlier explained, and 75% of this taken as the net amount to be processed for oil.

(4) The so-called Bergius method of processing coal or of a coal and oil mixture at high pressures with hydrogen has been developed in Germany to a semi-commercial scale. See F. Bergius, *Zeitschrift für angewandte Chemie* 34 (1921) 341-7; Graham & Shatwell, *Fuel*, 2 (1923), 54-7 (a review), also by same authors in *Fuel in Science and Practice*, January, 1925, pages 25-8; U. S. Pats. 1,342,790 (June 8, 1920) and 1,512,577 (Oct. 21, 1924).

Franz Fischer, director of the Institut-Mülheim for coal research, Berlin, in an address at the World Power Conference, London, 1924, on the Conversion of Coal into Oils (see *Colliery Guardian*, Vol. 128, 1924, pages 87-8), described his own work in this field as well as that of Bergius,

and confirmed the possibility of liquefying a large percentage of coal by this method. He expressed doubt, however, that "for the present" the production of light motor fuel by this method "was commercially realizable."

(5) Many processes of low-temperature coal distillation are reported in the technical press as under trial on a semi-commercial scale, and yields of products are given which cannot in all cases be substantiated.

The McIntire-Carbocoal primary retort now being operated on a one-unit industrial scale at Fairmont, W. Va., by C. V. McIntire, for Coverdale and Colpitts, Engineers, New York, is reported by McIntire in a letter to the author, dated Dec. 3, 1924, to be operating successfully on Pittsburgh coal, at the rate of 50 tons per day, producing 23-30 gallons of liquid fuel by-product, of which 80% will distill down to pitch coke. This retort and its operation are described in the recent report of the Giant Power Survey Board, Commonwealth of Pennsylvania, February, 1925.

Appendix C-IX, pp. 375-80.

The British (Government) Department of Scientific and Industrial Research, made a test, in July, 1924, of a commercial plant of low-temperature carbonization retorts (Parker System), at Barugh, Barnsley. Under unfavorable conditions (temperatures uneven and above the optimum range, leakage of air into retorts causing combustion and dilution of the gases, etc.), a yield of tar of 18.6 gallons per ton was obtained on a coal of 35% volatile.

The Thyssen rotary low-temperature carbonization retorts are reported to be operating in Germany, with yields of about 8% tar (or 20-21 gallons per ton). See review in "Chaleur et Industrie," 5 (1924), pages 127-8.

OIL PRODUCTION FROM U. S. LIGNITES

The data submitted below are collected from various sources, including the report of the Twelfth Geological Congress held at Ottawa, Canada, in 1913; published results of many tests on lignites by state and government bureaus; U. S. Bureau of Mines reports; tests by private companies published in technical journals; and various other sources of information. References to sources are given in order that further details may be obtained if desired.

It has been rather difficult to formulate a good average of the results obtained on distillation of the tar recovered in retorting the various lignites, since the various fractions

into which the tar is divided by different experimenters are not always comparable. A series of private investigations on lignites from different localities furnish a pretty fair criterion, however, and these indicate the results which, when others are averaged in, are given in the following tables with other data.

Regarding motor fuel obtainable from lignite tars, it is again difficult to form any exact opinion as to the quantity yields in the data published by various investigators. Cuts according to the temperature range may indicate volumes to be expected but it must also be considered from the quality standpoint where the amount of non-motor fuel constituent (such as tar-acids) must be taken into account. The best reliable data along these lines are given, also.

No effort has been made to reevaluate the coke residue obtained in distilling lignites. In general, it is not equivalent to either beehive coke, by-product coke, or gas coke, because the binding medium is not present and there results a granular and even powdery mass which may, and probably will, require special grates on which to burn. In Germany, their coke (called "Halbkoks" or "half-coke") made from lignite or brown coal, requires special stoves for burning.

Lignite Characteristics.—Where the various kinds of soft coals overlap to a great extent in their properties, it is difficult to set any limits for a given grade. However, arbitrary limits have been set and are given below (Ref. 1):

	Minimum, Per Cent	Maximum, Per Cent
Moisture.....	0.75	43.0
Volatile.....	27.0	53.0
Fixed carbon.....	16.0	51.0
Ash.....	2.6	42.0

In general, lignites contain considerable moisture, or rather, water, being often above 25% and nearer the upper rather than the lower limit.

The color of lignites is usually black but there also occur some brown and light-colored ones. Being so wet, there is a decided earthy appearance to them.

Occurrence.—The lignites are not nearly so widely distributed as the various coals (Ref. 2). They occur in only two of the great coal sub-divisions of the United States,—the Gulf Province (Texas and Arkansas) and the North Great Plains Province (North Dakota, South Dakota, Montana, Wyoming, Colorado, and New Mexico). About 98% occurs in the latter province and 2% in the former. The figures are as follows:

	Thousands of Tons (Short)
North Great Plains Province.....	965,000,000
Gulf Province.....	21,000,000
Total.....	986,000,000

Type of Carbonization.—Practically all work done on lignite carbonization has been at low temperature. By “low temperature” is usually understood temperatures below 1300° F. since it is assumed that the products formed first (called “primary products”) undergo no decomposition if they are not heated above this temperature. Whether or not this is a fact is not material since higher temperature would probably produce no better coke, and any cracking of the tars produced could be taken care of better by separately controlled cracking after tar recovery from the lignite carbonization.

No commercial apparatus has as yet proved entirely satisfactory in carbonization of the lignites. The high water content and tendency to disintegrate and become dust, form a difficult problem to overcome. In Europe, a very great number of retorts have been tried out commercially but none seems a complete and outstanding success although they operate. The trouble in the operation must be endured.

Products from Lignites.—The table below covering the products obtainable from lignites is made up, of necessity, mostly from laboratory results. The most extensive work done in this country has been carried out by the U. S. Bureau of Mines in cooperation with the University of North Dakota School of Mines. Large deposits of lignite occur in North Dakota. In the account of the work done by the U. S. Bureau of Mines, carbonization was carried out at various temperatures and the claim made that higher yields of tar were obtained at low temperatures, the best yield being obtained at about 700° F. Other investigators, however, do not completely check this result, higher temperatures giving greater speed of distillation and very little secondary decomposition judging by gaseous products and the quality of the tars.

The U. S. Bureau of Mines shows yields of tar as high as 11.0 gallons per ton of lignite, based on laboratory results. Commercial tests run by the same bureau gave a tar yield of about 2.0 gallons per ton. A sample of Washington State lignite (Tono District) run at the University of Washington laboratory, gave similar results to the U. S. Bureau of Mines laboratory results. A large number of other state samples gave tar yields of about 3 to 4 gallons when tested in the laboratory. The tables below show the individual results.

The average yield of products from lignite may be taken as the following:

Tar, gallons per ton.....	3
Gas, cubic foot per ton.....	4000
Gas, B.t.u. per cubic foot.....	400
Coke, pounds per ton.....	800

On the opposite page are given both laboratory and commercial results on various lignites. The data showing source, temperatures of treating, composition, etc., are shown under Reference 3 at the end of this report.

The above laboratory and commercial results show wide differences. In arriving at an average for the purpose of

LABORATORY YIELDS

(Per 2000 Lbs. Carbonized)

Sample	Approximate Temperature	Gallons, Dry Tar	Pounds, Coke	Cubic Feet, Gas	B.t.u. of Gas
(a)	800-1200° F.	3.6	889	5,920	478
(b)	800-1200° F.	4.7	848	5,550	416
(c)	800-1200° F.	1.3	800	5,710	408
(d)	800-1200° F.	3.0	790	6,100	407
(e)	800-1200° F.	2.5	662	6,100	449
(f)	800-1200° F.	3.2	700	5,780	419
(g)	700° F.	13.3	1008	4,400	
(h)	1200° F.	4.8	1310	12,000	476
(i)	600° F.	7.1	1100		
(j)	650° F.	9.3	1090		
(k)	700° F.	11.0	1050		
(m)	1025° F.	6.3	910	3,130	385
(p)	.....	16.3	1396	2,552	
(q)	.....	6.4	865	3,340	
(r)	.....	4.2	875	3,320	
(s)	.....	4.9	880	3,310	
(t)	.....	5.0	880	3,210	
(u)	.....	6.9	870	3,260	

COMMERCIAL YIELDS

(Per 2000 Lbs. Carbonized)

Sample	Approximate Temperature	Gallons, Dry Tar	Pounds, Coke	Cubic Feet, Gas	B.t.u. of Gas
(l)	.....	2.3	807	3,600	278
(n)	.....	4.2	780	1,600	110
(o)	980° F.	4.8	900	2,500	

evaluating the tar yield from *all* the estimated lignites in the ground, it must be kept in mind that the above samples were taken from *good* lignite deposits in practically every case, so it is thought that a fair average yield would be 3 gallons of tar per ton. This may prove to be too high as an average although it will probably be somewhat low for first

commercial plants which will naturally operate on the richest lignites obtainable.

Motor Fuel.—The quantity of light products which may be obtained from lignite tar and used as motor fuel is difficult properly to estimate. The distillation of lignite tar from low temperature carbonization of lignite will probably give about 0.5 gallon of light oil (to 400° F.), about 0.5 gallon of middle oil (400–600° F.), and the rest fuel oil and pitch.

It must be kept in mind that the raw distillate must be treated to remove tar acids and unsaturated products so that it can be used as motor fuel; otherwise, the motors will not handle it without changes in design and adjustments.

The results on the samples of lignite indicated above are as follows for motor fuel:

YIELDS, GALLONS PER 2000 LB. TON

Sample	0–400° F.	400–600° F.	Above 600° F.
(a)	1.3	1.5	0.8
(c)	0.4	0.4	0.4
(e)	.....	0.4	2.1
(f)	0.2	0.4	2.1
	Light Oil (?)	Medium Oil (?)	Paraffin Oil (?)
(g)	3.8	4.0	5.5
(h)	<u>248–400° F.</u>	<u>400–550° F.</u>	<u>Above 550° F.</u>
	1.2	1.7	1.9
(l)	<u>0–392° F.</u>	<u>392–600° F.</u>	<u>Above 600° F.</u>
	0.4	0.8	1.1
(n)	<u>0–392° F.</u>	<u>392–455° F.</u>	<u>455–520° F.</u>
	0.3	0.5	0.5

The above results, when corrected for the included tar acids and impurities that must be removed before good motor fuel can be obtained, show why an average of 0.5 gallon of motor fuel per ton of lignite has been selected. It must again be kept in mind that the above samples were selected while our estimate allows for poor lignites.

Conclusion.—In concluding, no attempt has been made to do more than interpret data—both published and private results,—and it must be pointed out that the quantity from which conclusions can be drawn is somewhat meager, and samples can not always be considered as average. It is natural to assume that all samples were taken to give best results if worked commercially, and that, if true, immediately raises the figures instead of giving averages. Taking this into account, we have arrived at the averages listed above which we assume will be near that obtained in long-time commercial workings.

REFERENCES

REF. 1. Treatise on Coal, by E. S. Moore, Dean of the School of Mines, Penna. State College.

REF. 2. Coal Resources of the World. Twelfth Geological Congress, 1913, U. S. authority, Marius R. Campbell.

REF. 3. *Lignite Samples—Source.*

- (a) Miles City, Montana (private experimental work).
- (b) Glendive, Montana (private experimental work).
- (c) Glendive, Montana (private experimental work).
- (d) Williston, N. D. (private experimental work).
- (e) Williston, N. D. (private experimental work).
- (f) Williston, N. D. (private experimental work).
- (g) Low Temperature Distillation of Lignite Coal from Tono, Wash., by H. K. Benson and L. L. Davis, Univ. of Wash., Journal of Ind. and Eng. Chem., Oct., 1917.
- (h) Production and Briquetting of Carbonized Lignite, by E. G. Babcock and W. W. Odell, U. S. B. of M. Bulletin 221, Oct., 1923. N. Dakota Lignite.
- (i) Same ref. as (h).
- (j) Same ref. as (h).
- (k) Same ref. as (h).
- (l) Same ref. as (h) Commercial, Incline Retorts.
- (m) Carbonization of Canadian Lignite, by Edgar Stansfield, Journal of Ind. and Eng. Chem., January, 1921. Lignite from Shand Mine, Souris Area, Saskatchewan.
- (n) Summary Report of Canadian Lignite Utilization Board, Jan. 1, 1924. Appendix 27.
- (o) A Process for the Economic Manufacture of Fuel from Texas Lignite, by Prof. E. P. Schoch, Journal of Ind. and Eng. Chem., Jan., 1921.

- (p) Carbonization of Texas Lignite by Carbocoal Process, Chem. and Met. Eng. Journal, Jan. 10, 1923. Lignite from Big Lump Lignite Co.
- (q) Same ref. as (n) Lignite from M. and S. Mine, Bienfait. Appendix 18.
- (r) Ref. (n) Lignite from Bienfait Mine, Bienfait.
- (s) Ref. (n) Lignite from Shand Mine, Shand.
- (t) Ref. (n) Lignite from C. and B. Mine, Esteran.
- (u) Ref. (n) Lignite from U. P. Mine, Taylorton.

REFERENCES—*Continued*

Analysis of Samples

Sample	Moisture at 220° F., Per Cent	Volatile, Per Cent	Fixed Carbon, Per Cent	Ash Per Cent
(a)	10.8	37.3	37.4	12.8
(b)	18.2	33.6	39.9	6.9
(c)	9.6	35.4	45.1	8.8
(d)	16.0	35.5	36.4	9.9
(e)	17.1	27.7	47.5	6.2
(f)	17.1	34.2	37.7	9.0
(g)	14.5	33.5	43.9	9.0
(h)	8.5	42.1	43.5	5.8
(i)	13.7	42.8	38.5	5.0
(j)	13.7	42.8	38.5	5.0
(k)	13.7	42.8	38.5	5.0
(l)	28.2	29.4	35.2	7.2
(m)	31.8	28.9	34.1	5.2
(n)	33.3	27.6	32.7	6.4
(o)	.....	.....	.....	.....
(p)	29.4	32.7	30.1	7.8
(q)	31.2	28.0	31.4	8.4
(r)	18.5	35.8	38.3	7.4
(s)	34.4	26.0	28.1	11.5
(t)	34.7	26.3	29.7	9.3
(u)	34.1	28.2	31.1	6.6

POSSIBLE UTILIZATION OF COAL RESIDUES FOR RECOVERY OF LIGHT MOTOR FUELS

BY

ROSS H. DICKSON

The methods and processes considered as a means of obtaining liquid fuel from coal have either been demonstrated through actual experiment and operation or they are a logical step in the development of present industrial practice.

The enormous amount of residual coke which would be produced if the total production of gasoline today were to be made from coal by low temperature carbonization is four or five times the quantity of coal which we are now producing for all purposes, so that undoubtedly any scheme in the future must consider using a lower grade of liquid fuel or else utilizing the residue in a manner different from coal of the present day. By this I mean that the generation of heat and power will have to be done in a different manner and probably a different place.

MEMORANDUM

In the low temperature carbonization of coal it is assumed that (per ton of coal) there would be produced between $2\frac{1}{2}$ and $3\frac{1}{2}$ gallons of light liquid fuel which may be usable in automotive engines. In the estimate so far no endeavor has been made to estimate what quantity of the total liquid products other than light spirits might be utilized for motor fuels. Also, nothing has been said in regard to the possibilities of use of the solid residue which ordinarily can be assumed to be a friable coke. Below we give what we believe to be a few of the possibilities under such circumstances.

Colloidal Fuel.—It was demonstrated during the war that a certain percentage of extremely finely divided coal could be suspended in fuel and utilized through liquid burners. There is reason to suppose that in the future this method might be further developed to the point where light products may support a colloidal suspension which could be fed to motors and utilized in that way. How much colloidal coal could be utilized is unknown.

Producer Gas Motors.—There has been developed and used commercially a system whereby a small gas producer is mounted on the back of a motor truck and supplies producer gas to the engine as fuel. The process has passed the experimental stage but under present conditions large scale use is not warranted due to inconveniences compared with the higher priced but more convenient liquid fuels. The proportion of coke which might be utilized in this way would probably be limited to the number of heavy burden vehicles such as trucks. There have been issued quite a few patents for various systems utilizing producer gas in this manner.

Alcohol from Coal.—Recently the American market has seen the influx of foreign-made methyl alcohol which has been made by the water gas process using coal as a starting point. Methyl alcohol, we understand, is not the only alcohol which may be made in this manner. The process consists, in its simplest form, of converting coal into a liquid fuel which, in this case, is an alcohol. The possibilities of the production of liquid fuel in this manner from coal or coke are very great and it is to be expected that the future will see great advances along this line. The conversion of gasoline motors to alcohol motors or mixture motors is not a very difficult proposition. The principal question here is simply one of the cost of such synthetic fuels.

Conversion to Electrical Power.—In accordance with several ideas which have been recently advanced, there seems to be a good possibility that the future will see the utilization of coal at its source in the production of electrical power

which will be distributed as far as economic limits will permit. There is no doubt but that such a scheme would include the distillation of the coal and recovery of by-products before conversion into electrical power. Conversely there appears to be equal possibility of utilizing the coke after necessary recovery of by-products, for the production of electrical power.

Conversion to Gas.—To-day billions of cubic feet of natural gas are being transported through pipe lines great distances to the consumers. In several instances coal is being converted into water gas and fed through the same pipe lines for the same purpose. In a scheme of recovery of liquid products from coal it seems reasonable to suppose that the gas from the by-products may be transported as natural gas is at present, and that the solid coke residue can be completely converted into gas and conveyed to its point of use through pipe lines.

Cracking Low Temperature Tar.—In the above and in usual calculations, very little account is taken of the heavier products which are obtained in the distillation of coal. From some preliminary work already done it seems reasonable to suppose that the total liquid by-products from coal may be subjected to a process whereby the light products may be doubled or tripled per ton. The quantity of residual coke would necessarily decrease in like proportion.

Liquefaction of Coal.—Considerable interest has been raised in the scientific world during the past ten years by the work done in Germany by Dr. Bergius, who is devoting considerable time to the hydrogenation of coal. It seems reasonable to suppose that by the time necessity compels the recovery of light products from coal, a process will be devised which will be economically possible and which will liquefy coal by the addition of hydrogen. A very great amount of work is still being done along these lines by various research organizations in Europe.

Heavier Fuels.—The present-day tendency is toward the use of heavier liquid fuels in automobile engines. At such a

future time when coals may be used as a source of liquid products, it seems reasonable to assume that the fuel will be a much heavier one than the present-day type, and that the design of the motor will have changed to suit the heavier fuel. The possibility of using residues is not very remote and colloidal fuels as well as straight heavier fuels may be used. This again will cut down the total quantity of coal necessary to treat to obtain adequate supplies.

Pulverized Direct Fuel.—Regarding the direct use of powdered coal in explosion motors, developments may prove that this will be entirely possible. If such proves to be the case the coke made by removing all volatile constituents will prove ideal as a starting point for the pulverized fuel.

PART III

REPORT ON THE PROBABLE FUTURE
DEMAND FOR PETROLEUM IN
THE UNITED STATES

I. PURPOSE AND SCOPE OF REPORT

The purpose of this report is to forecast the future demand for petroleum within the continental United States over such a period as present conditions seem to indicate that a reasonable estimate is justified. A study of a number of industries outside of the petroleum industry was made, and several agencies familiar with economic research were consulted. From these consultations and analyses, a period of twenty-five years was chosen as a safe time over which to make a reasonable estimate, with an additional period of twenty-five years of a more speculative character as indicated by an extension of the trend of the curves. The latter part of the curves, from 1950 to 1975, is intended for the purpose of indicating relationships rather than specific figures.

When this study was first begun an effort was made to forecast the future demand for a period of one hundred and seventy-five years. Owing to so many uncertain factors this proved impracticable and the scope of the report was reduced to a period of fifty years.

In this report the peace time demand for petroleum has been developed by making an independent estimate for each of the three most important products—gasoline or equivalent fuel, lubricating oil and fuel oil.

The crude oil demand has been estimated from the gasoline and lubricating oil requirements only, it being considered that the demand for these two products would be met from the crude first, and any residue incidental to manufacturing could be used as fuel oil. Furthermore, from our present knowledge it would be much easier to find substitutes for fuel oil. Kerosene and other miscellaneous products have been included in the fuel oil. The supply of crude oil from oil shale and coal was taken into account in a very limited manner for the sake of comparison as will be

explained hereafter. No consideration has been given to price, imports or exports, in order to emphasize the position of this country independent of any other resource.

For the complete solution of the problem implied, the results of this investigation should be correlated with an analysis of petroleum supply. This is not practical, however, due to the impossibility of predicting the rate at which petroleum supply will be withdrawn from the underground reservoirs, or the rates of development of other sources of supply and substitutes. Because of these unknown factors, the problem has been handled by showing two separate conditions of demand throughout the report. The first, a maximum demand, is based on the continuation of present methods and utilization, with present tendencies toward conversions to electricity and Diesel engines. The second condition assumes immediate changes to all present known possible improvements and increased efficiencies in manufacturing and utilization. Supply has therefore not been considered in the present study, except insofar as a general conception of availability has been found necessary to guide estimates of rates of conversion from one source of energy to another, and in showing to what extent our auxiliary reserves, such as coal and shale, might be depleted by the demand as predicted.

War or other emergency conditions have not been considered in this report. A study of this problem was made, however, by comparing industrial conditions during the last war period with peace-time conditions. There was no apparent abnormal increase in the total power consumed by industries, but there was a redistribution of energy giving to essential industries at the expense of others. It has, therefore, been assumed that in case of emergency the power demand on land could easily be manipulated or curtailed to leave adequate supplies of the desired fuel when it is needed.

II. Definitions.—Barrels of 42 gallons each have been considered in all barrelage computations throughout this report.

In order to avoid confusion in referring to the various petroleum products, the following definitions are given:

(1) *Gasoline* or *equivalent* is any fuel that may be used in any engine similar to the popular gas engine of today, making use of the carburetor principle; for example motor fuel from oil shale or coal, or alcohol.

(2) *Lubricating oil* throughout the report refers to a lubricant that may be obtained from some form of liquid petroleum, as the natural product from wells, oil from oil shale, or oil from the low temperature distillation of coal.

(3) *Fuel oil* including *Diesel oil*, and excepting gasoline, is intended to mean any liquid petroleum suitable as a fuel, derived from natural petroleum, oil shale or coal.

(4) *Crude oil*, as the term implies, is the raw product which may come from any available source.

III. Conclusions.—The conclusions which may be drawn from this investigation relative to the probable future demand for petroleum in the United States may be briefly summarized as follows: (In this discussion, figures to the nearest hundred thousand only will be quoted.)

(1) The estimated maximum gasoline requirements based on future growth of automobiles, trucks, aeroplanes, motorcycles, motorboats and industrial use, should increase in accordance with population and industrial growth, from a present consumption of 185,000,000 barrels in 1924 to 315,400,000 barrels in 1930. Due to a slowing up in the increase of automotive engines, it is not expected that there will be as large an increase in consumption for the ten-year period from 1930 to 1940 as probably will be made in the five years previous to 1930. An estimate of 403,000,000 barrels was made for 1940 or more than double the amount now required. During the next ten-year period an increase of 52,500,000 barrels is expected or a total maximum demand in 1950 of 455,500,000 barrels. Should this trend continue for another twenty-five years, or until 1975, there will be a consumption of 547,100,000 barrels of gasoline

or approximately three times as much gasoline as was consumed in 1924.

The above figures do not take into consideration improvement in utilization or increased efficiency. From reliable sources, however, (see Appendix C, page 236), the present automotive efficiency could be doubled and if this were effected within the next five years, it would be possible to satisfy the trade in 1930 with less gasoline than was used in 1924.

In 1940, or fifteen years from now, an estimated minimum consumption of 201,500,000 barrels would be slightly in excess of present needs. Ten years more would only bring the demand up to 227,700,000 barrels, while during the year 1975 the estimated requirements would reach 273,500,000 barrels or a little less than one and one-half times the consumption for 1924.

(2) Lubricating oil requirements should be influenced by the growth of automotive engines and industries. From a composite curve composed of these two controlling factors, the estimated maximum lubricating oil requirements should increase from 18,000,000 barrels in 1924 to 28,000,000 in 1930 which would mean an increase of over 50%. An increase of approximately 10,000,000 barrels in the annual consumption is anticipated by 1940 which would result in a consumption of 38,000,000 barrels for that year. It will be noted that no greater gain is expected for this ten-year period than for the five years previous to 1930.

A similar increase for the ten years following 1940 gives an estimated maximum demand for 1950 of 48,000,000 which means that twenty-five years from now the annual consumption would be over two and one-half times as much as is now being used. The anticipated trend, if extended to 1975, would give an annual consumption during that year of 68,400,000 barrels which, measured in terms of 1924 consumption, would represent almost four times present-day needs.

With the introduction of improved bearings, more

general practice of reclaiming used oil, and other improvements in conservation, the estimated demand should be reduced by one-half (Appendix F, page 240). This would result in a minimum requirement for 1930 of approximately 4,000,000 barrels less than is now used.

In 1940 the minimum demand would be in excess of the 1924 consumption by only 1,000,000 barrels or would equal 19,300,000 barrels. Ten years in advance would bring the consumption up to 24,000,000 for 1950 or one and one-third times the 1924 figure. If the anticipated rate of increase follows the assumption made, there would be an annual minimum consumption of 34,000,000 barrels in 1975 or less than twice what is now needed to satisfy the trade.

(3) The crude oil demand has been estimated on the basis of the amount that would be necessary to supply the estimated requirements for gasoline and lubricating oil. Continuing with the present trend and without consideration of well-known possible improvements in refining, it would require a maximum production of over a billion barrels during 1930 to furnish these two products.

In 1940, the maximum demand would be more than double the amount used in 1924 for gasoline and lubricating oil, and in 1950, the requirements will have reached almost one and one-half billion barrels (1,500,000,000). The estimated rate of increase would give an estimated maximum consumption for 1975 of one billion, eight hundred million (1,800,000,000) barrels or practically three times the amount used in making gasoline and lubricating oil in 1924.

Fortunately, when economic conditions permit, there are possible methods known at the present time in the manufacturing processes which will result in a greater yield of light products from the crude than is now being obtained. Taking these improvements into consideration, results are obtained that are much more favorable than those just cited.

In 1930, if all improvements were put into universal practice, it would be possible to obtain gasoline and lubricating oil from a quantity of crude slightly over one-half

of what was used in 1924 for this purpose. The estimated minimum requirement for 1940 would reach 430,700,000 barrels or a little over two-thirds of present requirements, while in 1950 the demand would be 490,000,000 barrels, which is still 125,000,000 barrels less than the present-day needs.

The amount of crude required for gasoline and lubricating oil would approach the present-day demand for crude for this purpose at about 1975, with an estimated minimum consumption of 598,500,000 barrels.

(4) The demand for fuel oil has been approached from two angles; first, by assuming that it would be forced by economic pressure to conform to the quantity of residuum left from the manufacture of gasoline and lubricants; and second, by considering the predicted growth of industrial uses to which fuel oil is peculiarly adapted as a source of energy.

The fuel oil requirements for the future are problematical, due to the fact that ready substitutes are always available to replace this source of power whenever such replacement becomes economically practicable. It is quite evident that, with the improvement in refinery practice, the volume of resultant residue or fuel oil will become less and less until this source of fuel will not be adequate to satisfy the demand on a price basis competitive with coal. This will lead to the gradual conversion to other fuels, particularly coal, or to other sources of power—without inconvenience to the public; however, it is important to know that even under the highest known efficiency in refinery operations at this time, there would be more than sufficient residue which could be used as fuel to take care of the maximum requirements of the U. S. Navy and Merchant Marine and a demand restricted to 5% of the estimated maximum industrial needs.

The consumption of fuel oil is now approximately 390,000,000 barrels annually which is estimated will increase to 455,000,000 barrels in 1930 as a maximum estimate.

During the next ten-year period or until 1940, a slower rate of increase is anticipated than during the previous five-year period, due to conversions to other sources of power and changes in mechanical equipment, which results in an estimated maximum consumption in 1940 of 573,000,000 barrels. For the year 1950, twenty-five years from now, a maximum demand of 641,000,000 barrels has been predicted, or slightly over one and one-half times present-day needs.

If the present tendency toward conversion to other sources of power and changes in mechanical equipment resulting in higher efficiency continue, during the year 1975 there would be a maximum consumption of 840,000,000 barrels, which is more than twice the requirement at the present time.

Considering only that use for fuel oil for which it is manifestly far superior to any other known fuel at the present time, namely, the U. S. Navy and the Merchant Marine, it is estimated that the maximum demand for ocean transportation will increase to 67,000,000 barrels annually in 1930, reaching a peak in 1940 with a consumption of 75,000,000 barrels. Thereafter, due to conversion to more efficient mechanical equipment, it is expected that the consumption will become gradually less. For this reason, the maximum requirement in 1950 would be 71,000,000 barrels or approximately only 15,000,000 barrels above the present demand.

At the rate predicted, conversion to more efficient equipment would not be completed until around 1960 which would give a low figure in consumption, probably less than actual requirements at the present time. After this, the demand would be expected to increase, giving a maximum consumption in 1975 of 68,000,000 barrels, which indicates that throughout the entire fifty-year period, there may not be any very great change in the demand over present requirements by the U. S. Merchant Marine and the Navy.

(5) While this report has to deal only with the demand for petroleum, it is of interest for comparative purposes to note what effect the estimated demand for gasoline or equivalent fuel will have toward using up the reserves of shale on the assumption that other sources of supply were immediately cut off.

With the figures furnished by the "Supply Group" of the "Committee of Eleven" of the A.P.I. on the estimated supply of shale and recoverable light motor fuel as a basis, computations have been based on a yield of 3 gallons of motor fuel per ton of shale which show that during the next twenty-five years, the estimated maximum demand for gasoline or equivalent fuel could be supplied and the shale reserves depleted only 33%. The computations show further that by the end of the year 1975 approximately 78% of the shale reserves would have been used up during the fifty-year period.

If an analysis is made on the basis of a six-gallon yield per ton of shale, it is estimated that at the end of 1950, the shale oil reserves would be depleted 16.5%, and at the end of a fifty-year period or 1975, 39% of the estimated reserves would be used up which still leaves a considerable portion for further exploitation.

In addition to shale, there is also the possibility of coal to consider as a source of fuel. From the figures given by the "Supply Group" of the A.P.I. on the estimated reserves of coal, with the crude oil and light motor oil obtainable therefrom, computations have been made to indicate the rate of depletion of these reserves for the next fifty years, provided this were the only available source for petroleum supplies.

It is found that, on the basis of the predicted maximum demand for all fuels and lubricating oils, only 9% of the coal would be consumed by 1950 and at the end of 1975, 21% would have been used. This rather emphasizes the magnitude of these potential reserves.

IV. Method of Attack.—For a period extending fifty

years into the future, only the broadest secular trends which depend upon fundamental laws and which are normal continuations of long established growth, can be rationally forecasted. National population and general industrial growth offer the only sound basis for such a forecast, and these two factors form the foundation of this analysis.

Predictions of narrower phases of our social or industrial life can be made only on the basis of an assumed relationship to one—or both—of these two fundamental growth forecasts. Within this class come predictions of automotive transportation, both pleasure and commercial, predictions of railway ton mileage, of power generation by central stations, etc. From such "secondary" forecasts the trend of increasing energy demand can be determined for any one, or for all, of our important power-consuming activities.

Next, by assuming rates of conversion from one source of energy to another for each group of power users, an idea may be had as to the quantities of the various energy sources which must be available from decade to decade to keep pace with normal national development. Since the effect on demand of depleted resources and consequent increased price cannot be readily estimated without a knowledge of the quantities available, the rates of conversion cannot, in most cases, be defended beyond saying that they do not appear unreasonable.

To arrive at a final estimate of the amount of oil necessary to supply the energy dependent upon it requires one further step into the realm of speculation, namely, predicting advances in the efficiency of energy utilization. Such advances may result not only from improvements in present types of equipment, but also by the introduction of those radically different. In this study no attempt has been made to draw this line finely; it was considered wiser to indicate a range of demand limited by maximum and minimum estimates.

V. Basis of Analysis.—This study is based, as any study of its kind must be, partly on *facts* and partly on *assumptions*.

In interpreting figures and charts, and in appraising conclusions, the distinction and gradation between the two should be borne in mind.

Certain assumptions, such as that concerning population growth, are tied so closely to well-grounded laws that there is little chance for significant error to creep in. Others, such as the rate of conversion from steam to Diesel-driven electric generators, are highly speculative. As predictions tend toward the latter class they should be looked upon as indicating relative tendencies rather than absolute quantities.

Throughout the report references are made to the sources of information used or authorities quoted. In general, actual values are given for the past five years. Where assumptions are made to supplement or take the place of facts of record, they are clearly indicated as assumptions and, where warranted, supporting reasons are given for their choice.

VI. Predictions.—In general, all predictions are considered in two phases: first, that in which growth is determinable by extending present trend; and second, that in which growth is a function of population.

Forecasts during the first phase are based upon actual past records and present trends. During the second phase the extension of this trend is made to tend toward the population growth rate.

Population is, therefore, not only the dominant influence throughout most of the fifty-year period considered, but fortunately is also the thing of which we can be most certain in the future. The method of making this prediction is explained in detail later.

Next in importance to population growth, as a determinant of all other development trends, is the growth of our combined industries. For this prediction, the actual trend for the past one hundred years can be projected ahead through the first forecasting phase, and then modified according to fairly well-established influences of population, trend

of exports and imports, and trend of per capita wealth of the nation. In this we can be more or less guided by the industrial history of European countries 100 to 150 years farther along than we are in the cycle of national development. All other industries and major activities are also ultimately subordinate to these two great factors in national development.

In general, throughout the report, full advantage has been taken of all available forecasts germane to the problem, and wherever there was considerable difference between the results arrived at by an independent analysis, and those calculated by outside authorities, the method which would give the largest consumption was chosen. This was done in order to secure figures that would meet the highest reasonable expectations.

Those particular phases of the problem which can be developed as some function of population or industrial growth rest upon a reasonably sound basis; on the other hand, predictions which involve conversion from one form of energy source to another, and are further complicated by the influence of supply and demand on price, must be considered highly conjectural.

VII. General Discussion of Suggested Methods for Decreasing the Demand for Petroleum in the United States. It is not believed that a report of this kind would be complete without a few suggestions as to ways of effecting savings in the consumption of petroleum. Those which follow by no means exhaust the possibilities, but are selected for their outstanding importance and unquestionable practicability.

(1) Educate the public to more efficient use of fuel in present equipment, so that equal quantities of fuel will deliver more work.

The low prices that have held for fuels, both gasoline and fuel oil, in recent years, have encouraged wasteful tendencies in the habits of the consuming public. The average

motorist pays comparatively little attention to the actual gasoline mileage obtained due to the proportionately small part the item of fuel cost plays in his operating expenses; but were proper investigation made, a very simple adjustment in his fuel mixture might be the means of saving millions of gallons of this fuel for the year.

The results of tests made by the Bureau of Mines have shown that the average motor vehicle wastes approximately 30% of the heat value of the fuel used, mainly due to improper carburetor adjustment. In one set of tests made by the Bureau, based on exhaust gas analysis, it was found that the increased gasoline mileage due to proper carburetor adjustment ranged from 36% to 106%. A similar saving can be obtained in the use of fuel oil by adjusting the burner to use the proper amount of air. Savings such as these will extend our potential supply over a correspondingly longer period of time.

(2) Improve present equipment and create new equipment to give higher efficiency in order to conserve fuel.

The automobile engine of today converts only about 5% of the fuel energy consumed into actual performance, the balance being consumed in overcoming friction, wasted heat, etc., having to do with the mechanical working of the machine. A broad field for conservation, therefore, presents itself along lines of improvements in this engine, or the invention of new machines as substitutes which will operate at higher efficiency. In some instances, this is being practiced to-day in other directions by the substituting of motor ships for steamships, resulting in a vast saving in the consumption of fuel oil. This not only applies to machinery which uses petroleum products for fuel, but also to coal burning equipment. If fire boxes and boilers can be improved so as to deliver a higher efficiency when burning coal, the replacing of oil fuel by coal fuel will be made that much easier. The petroleum conservation program, there-

fore, should be materially benefited by any improvements made in coal burning equipment.

(3) Encourage more general use of Diesel engine.

The Diesel engine promises to be one of the most effective developments in prolonging the life of our petroleum supply. This type of engine, if successfully developed to take the place of our present popular gasoline engine, by the elimination of excessive weight, increased flexibility in handling, etc., would have the effect of multiplying the available supplies of motor fuel six times, provided that the motor fuel used was extracted from some form of crude. The popular gas engine now utilizes about 25% of the crude, whereas the Diesel engine would utilize 100% of the crude, and the gas engine has only approximately two-thirds the thermal efficiency of a Diesel engine.

(4) Increased price of petroleum products will:

- (a) Eliminate waste in consumption
- (b) Prevent use of fuel oil in competition with coal or other means of securing power, such as electricity, etc.

The current prices of petroleum, to a great extent, appear to have a direct bearing on conservation of the products, as well as of the crude itself. With the price sufficiently high, the consumer will devote more attention to possible ways of reducing waste in his operations, whereas, with low prices he considers this factor as negligible from a cost viewpoint.

As long as fuel oil sells at a low figure, many industries which should be using coal as fuel will use fuel oil in preference, due to the ease in handling, etc. Under present economic conditions this cannot be avoided. Should the law of supply and demand ultimately cause an upward revision in prices, the effect produced will be not only to limit com-

petition with cheaper fuel, but to bring into use other fuels.

VIII. Method of Presenting Data.—The results of this investigation have been presented in the form of tabulated data and graphic charts. Complete explanations of the methods followed precede these data in each instance. Wherever available, actual records for the past five years have been plotted annually. The estimated figures which were obtained by the various computations were then plotted for each five-year period for the next fifty years, or until 1975. Through these points, normal curves were drawn to indicate the predicted trend or growth of the various factors comprising the study.

IX. Summary on Derivation of Curves.—Such an estimate as this must be interpreted as covering broad relationships rather than specific figures. As stated above, the only sound basis for establishing the trend of such relationships is increase in population and in industrial growth. These two main factors form the foundation of this report. The population curve is based on the formula of Raymond Pearl and Lowell J. Reed of Johns Hopkins University, who are authorities on this subject. The American Telephone and Telegraph Company have made estimates of population up to 1950 which check very closely with this estimate.

In conjunction with the population curve, two industrial growth curves "A" and "B" have been used, one of which (curve "B") was developed and submitted by the "Harvard Economic Service" (See Appendix A, page 229) at the request of the American Petroleum Institute.

The other industrial curve (curve "A") was developed from a detailed study of the primary horse-power used in the principal industries of this country for the past fifty to one hundred years, as shown by the U. S. Bureau of Census figures, and by other authorities. The trend of this curve was also checked against industrial development curves of some of the older countries, such as Germany and France, as related to their population growth.

Curve "A" gives a greater increase in industrial development than curve "B," hence by its use larger results in connection with consumption are obtained.

The curves showing increase in population and industrial growth have been taken as the fundamental basis of estimating the future requirements of liquid fuel and lubricants. From these curves has been developed a curve showing the growth in use of automotive engines. This automotive engine curve has been compiled from three curves:

First. A curve for passenger automobiles;

Second. A curve for motor trucks, and

Third. A curve for aeroplanes, motor boats and motorcycles.

Tractors have not been included under the heading of automotive engines for the reason that an attempt has been made to classify as automotive engines only those requiring gasoline as fuel while the tendency in tractors is toward the use of a heavy fuel and has been considered under industrial energy. The saturation point for passenger automobiles has been fixed at one car for each family. (See Appendix B, page 234.) A study of the U. S. Bureau of Census figures indicates that in the very near future the average family in the United States will be represented by four persons. (See page 188.) The passenger automobile curve as related to population and industrial growth curves indicates that by about 1940 we will have arrived at the saturation point of passenger cars. The curve showing the increased use of motor trucks has been developed in accordance with population and industrial growth. The curve for aeroplanes, motor boats and motorcycles is based on present tendencies toward increases and is a difficult one to chart with precision, particularly with reference to aeroplanes.

Gasoline.—Three gasoline curves have been plotted:

First. A maximum consumption curve based on curve "A," using an average of 10.1 barrels (42 gallons) annually, which is the average consumption per automotive engine for the last seven years, for use in automotive engines; and

the amount required for industrial use which has been increased according to industrial growth.

Second. A similar curve based on Curve "B."

Third. A minimum consumption curve based on an assumed doubling of the efficiency of the present automotive engine and more efficient use of industrial gasoline, requiring but 50% of the fuel shown in the first curve.

As a justification of the establishment of this minimum gasoline consumption curve, we have the opinion of such eminent authorities as C. F. Kettering, President of the General Motors Research Corporation, and H. L. Horning, President of the Society of Automotive Engineers (See Appendix C, page 236).

Lubricating Oil.—In the same manner that the gasoline curve was plotted, two curves have been plotted for lubricating oil consumption (i.e., maximum and minimum). The maximum curve is on the basis of an annual consumption of three-fifths of a barrel (42 gallons) per automotive engine per annum. Industrial requirements were determined by deducting from the domestic consumption of lubricating oil, as reported by the U. S. Bureau of Mines, the amount of lubricating oil used for automotive engines on the above basis and assuming that the remainder was the quantity needed by industries. The industrial lubricating oil requirements were projected at the same rate of increase as industrial growth curves "A" and "B", while the automotive lubricating requirements were projected on a curve parallel to the automotive curve. The minimum lubricating requirements curve is a theoretical one established at 50% of the maximum curve. This assumption is justified on the basis of greater economy in the use of lubricants (such as reclaiming used oil, improvement in bearings, and other mechanical features).

Crude Oil.—Having thus established maximum and minimum requirements of both gasoline and lubricating oils, a curve has been established showing the maximum and minimum requirements of crude oil from which these prod-

ucts are to be derived. In establishing the maximum crude oil curve present tendencies for lubricating and gasoline extraction have been used and on the basis of the maximum consumption curve of both gasoline and lubricating oils. The minimum crude oil consumption curve is based on the minimum gasoline and lubricating oil requirements as described above and assuming the highest yield of each product from the crude by present known possible methods.

Fuel Oil.—Starting with the present annual energy demand in the United States, on a basis of horse-power hours, and guided by the industrial growth and population curves, there has been plotted a curve representing the future trend of energy requirements. This curve, in turn, has been segregated into four components of energy, as follows:

- (1) Hydraulic power
- (2) Gasoline
- (3) Fuel oil
- (4) Coal

Taking into consideration the present tendency of the various rates of conversion and the present tendency toward increased efficiency values, two estimates of the energy demand for fuel oil have been made, one based on the Harvard Industrial curve "B" and the other based on an independent industrial curve, "A", which latter curve might be designated as a maximum demand estimate.

It has been further assumed that requirements of the United States Merchant Marine and Navy might be considered as the most essential use for fuel oil. These figures, which have been included in both estimates of energy demand for fuel oil, are segregated in order to bring out the relationship between the estimated ocean transportation requirements and the estimated total demand. This curve would represent a possible minimum demand estimate.

Another segregation is made showing the ocean transportation demand and a very limited land use of 5% of the estimated industrial requirements.

X. Detailed Discussion on Derivation of Curves.—

POPULATION IN THE UNITED STATES

PLATE I CURVE I

Population estimate is based on the formula of Raymond Pearl and Lowell J. Reed of Johns Hopkins University. Reference Proceedings of National Academy of Science, June 15, 1920, Vol. 6, page 278.

$$y = \frac{2930.3009}{e^{-0.0313395x} + 0.014854}$$

when

y = estimated population in thousands;
 2930.3009 = constant of the empirical equation
 determined by considering the
 population of various years from
 1780 to date;
 e = limit of exponential series (2.71828);
 x = number of years since 1780.

COMPARISON OF ACTUAL POPULATION FIGURES (1790-1920) WITH
 FIGURES OBTAINED BY USE OF PEARL'S FORMULA

Authority: National Academy of Science Proceedings, Vol. 6, 1920, p. 284

Year	Observed Population	Calculated Formula by Equation	Per Cent Error
1790	3,929,000	3,929,000	0
1800	5,308,000	5,336,000	+0.52
1810	7,240,000	7,228,000	-0.17
1820	9,638,000	9,757,000	+1.23
1830	12,866,000	13,109,000	+1.89
1840	17,069,000	17,506,000	+2.56
1850	23,192,000	23,192,000	0
1860	31,443,000	30,412,000	-3.28
1870	38,558,000	39,372,000	+2.11
1880	50,156,000	50,177,000	+0.05
1890	62,948,000	62,769,000	-0.28
1900	75,995,000	76,870,000	+1.15
1910	91,972,000	91,972,000	0
1920	106,418,000	107,320,000	+0.85

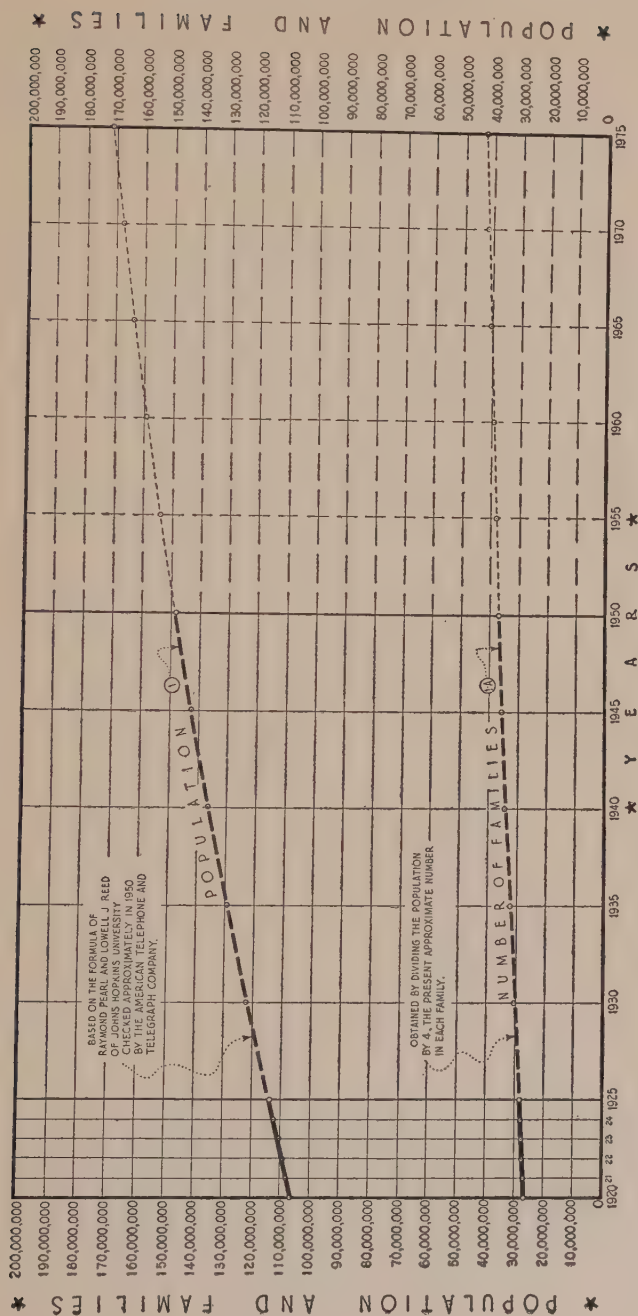


PLATE I.—ESTIMATED FUTURE POPULATION OF THE UNITED STATES.

The American Telephone and Telegraph Company has estimated a population of about 150,000,000 in 1950.† This checks our estimate of 149,000,000 in 1950. Other estimates from various sources have agreed closely with our figures.

NUMBER OF FAMILIES

PLATE I CURVE I-A

This curve was obtained by dividing the population figures by 4, that being approximately the number in each census family at the present time. This curve was used as a guide for determining the saturation point for passenger cars, it being assumed that ultimately there would be at least one passenger car per family.

AVERAGE PERSONS PER FAMILY IN UNITED STATES †

Date	Population	Number of Families	Persons per Family
1830	12,866,000		
1840	17,069,000		
1850	23,191,000	3,598,000 *	6.4
1860	31,443,000	5,210,000 *	6.0
1870	38,558,000	7,579,000	5.1
1880	50,155,000	9,945,000	5.0
1890	62,947,000	12,800,000	4.9
1900	75,994,000	16,170,000	4.7
1910	91,972,000	20,400,000	4.5
1920	106,418,000	24,800,000	4.3

* Estimated

† Statistical Abstracts of United States, 1923, 1920, 1910, etc.

‡ Bell Telephone Quarterly, January 1924.

TABLE I.—ESTIMATED FUTURE POPULATION OF THE UNITED STATES

(Plate I)

Year	Population (Curve 1)	Number of Families (Curve 1-A)
1920	106,418,000	26,604,000
1921	107,833,000	26,958,000
1922	109,248,000	27,312,000
1923	110,663,000	27,665,000
1924	112,079,000	28,019,000
1925	113,494,000	28,373,000
1930	122,397,000	30,599,000
1935	129,527,000	32,382,000
1940	136,318,000	34,080,000
1945	142,712,000	35,678,000
1950	148,678,000	37,170,000
1955	154,100,000	38,525,000
1960	159,230,000	39,808,000
1965	163,900,000	40,975,000
1970	167,945,000	41,986,000
1975	171,654,000	42,913,000

INDUSTRIAL GROWTH

PLATE II CURVES "A" AND "B"

In conjunction with the population curve, an industrial development curve has been used extensively. This curve was required as a basis for predicting the total energy demand for manufacturing industries. It was also used in predicting the demand for lubricants and commercial gasoline and, in a measure, to forecast the trend of transportation (railroad, motor truck and aeroplane) as well as ocean transportation and public utility electricity.

Two independent estimates of the growth of industry in the United States have been developed, the results of which are expressed by two basic curves, to be designated hereafter as curves "A" and "B". Curve "A" gives a faster rate of growth than curve "B", hence by its use, larger consumption figures will result. As it was desired to forecast a maximum demand for petroleum which could be

considered safely large enough under any emergency, curve "A" has been given preference throughout the report. The results obtained by using curve "B" are also given in order to show the difference between the two methods.

INDUSTRIAL GROWTH CURVE "A"

To determine the trend of industrial growth prior to 1920, the horse-power used in each of 28 important industries and their quantity production (as given in the 14th Census of Manufactures) were plotted on ratio paper for the past fifty to one hundred years. Other significant data, including Day's Manufacturing Indices (Harvard Economic Service) were likewise plotted. These curves exhibited so nearly the same secular trend that a representative curve showing the rate of industrial growth could be established with fair accuracy. The Industrial Growth curve "A" (Plate II) was accordingly plotted up to 1920, using as a guide the figures for total primary horse-power used in the U. S. since 1860. During the past fifty years, industrial activity has increased approximately as the third power of the population.

The Industrial Growth curve "A" was then projected into the future, taking into consideration the fact that the domestic demand for manufactured products is yet far from satisfied, and that even as production approaches domestic demand, the rate of industrial growth will remain above that of population due to the combined influences of increasing export rate, increasing per capita wealth, and increasing complexity of economic organization. Rate curves were plotted for France and Germany showing population, industrial growth, manufacturing industries, and exports. Their population curves were fitted to the predicted population curve of the United States to determine corresponding periods, and their rates of manufacturing and export development were likewise used as rough guides for predicting the future trend, all with proper allowance for special factors affecting the economic development of those countries.

A discussion follows of the more important curves used in conjunction with the Industrial Growth curve "A":

Railway ton Miles.—The average ton miles of freight hauled by railroads annually in five-year periods were plotted from 1890 to 1920 (Statistical Abstract of the U. S.—1923) and from observation this trend was projected to 1975 based on the estimated industrial growth and population for the corresponding periods.

This prediction was subsequently found to check almost exactly with the forecast to 1945 made by the Valuation Analyst of the Interstate Commerce Commission (J. B. Blood).

U. S. Merchant Marine (Gross Tons).—The gross tonnage of American Merchant Marine was plotted from 1880 to 1920 (Statistical Abstract of U. S.—1923) and projected to 1975, based on industrial growth and population.

Total Exports—Deflated Value.—Values of total exports since 1820 were deflated according to indices furnished by the Federal Reserve Bank (12th District). The line on Plate II—Figure 1, indicates the secular trend of exports during the past one hundred years.

Per Capita Wealth—Deflated Value.—Data were taken from Statistical Abstract of U. S., 1922, page 646, and were corrected to take care of deflated value. The curve represents a secular trend.

Data for the industrial and population curves for France and Germany were taken from the Mulhall Dictionary of Statistics (4th Edition) and The Statesman's Yearbook, and for the various manufacturing curves from Statistical Abstracts of the U. S., Abstract of Census of Manufactures and other sources.

INDUSTRIAL GROWTH CURVE "B"

Curve "B" was developed by the "Harvard Economic Service," who very kindly offered to cooperate with the A.P.I. and gave their views regarding industrial development from 1900 to 1950. A detailed description of the derivation of this curve will be found under Appendix A, page 229.

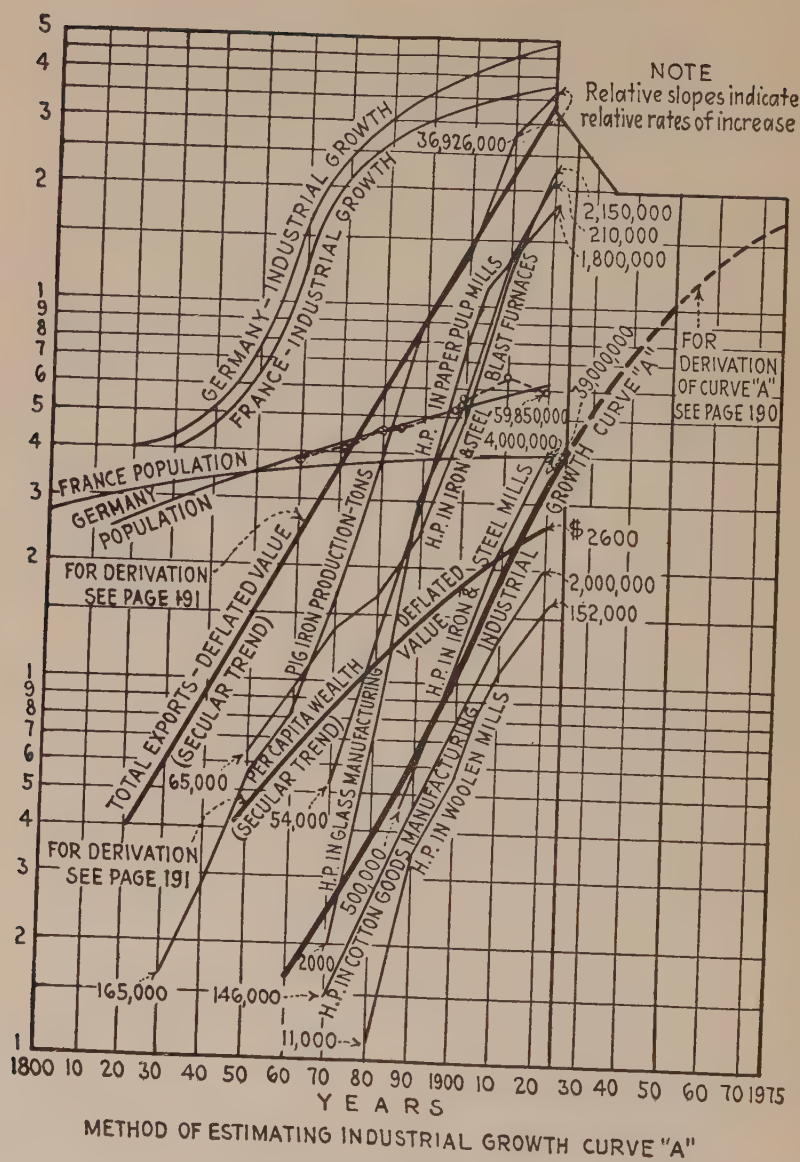
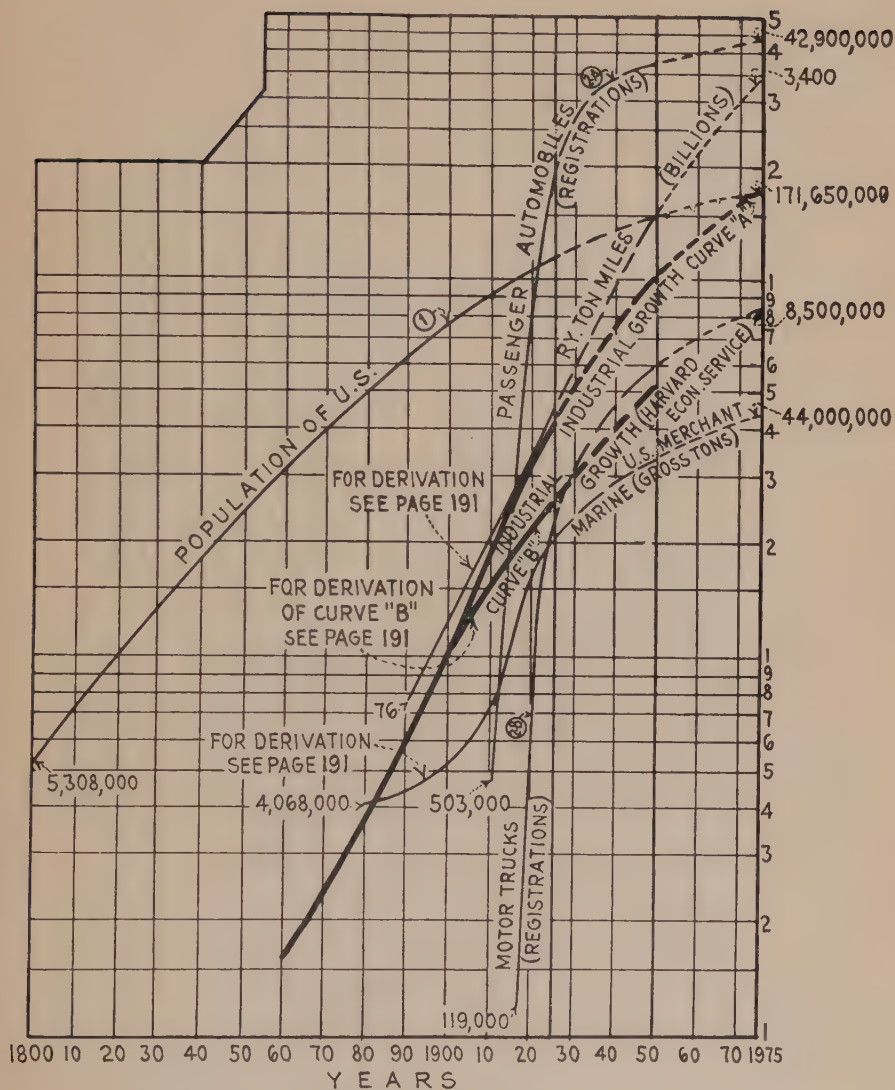


PLATE II.—ESTIMATED FUTURE RATES OF



COMPARATIVE ESTIMATED RATES OF DEVELOPMENT

DEVELOPMENT IN THE UNITED STATES.

TABLE II.—ESTIMATED FUTURE RATES OF DEVELOPMENT
IN THE UNITED STATES
(Plate II)

Year	Total Exports, Thousands of Dollars *	Wholesale Price Index †	Total Exports, Deflated Value, Thousands of Dollars	Index Number 1920 = 100
1840	123,669	104	118,912	3.39
1850	144,376	91	158,654	4.53
1860	333,576	89	374,805	10.68
1870	392,772	127	309,269	8.80
1880	835,639	96	870,457	24.78
1890	857,829	83	1,033,529	29.42
1900	1,394,483	83	1,680,100	47.85
1910	1,744,985	103	1,694,160	48.25
1920	8,108,989	231	3,510,385	100.00

Year	Primary Horse-power Used in Manufacturing ‡	Index Number, 1919 = 100	Year	Horse-power in Iron and Steel Mills ||	Index Number 1920 = 100
1869	2,346,142	7.95	1888	500,000 ¶	12.50
1879	3,410,837	11.56	1899	1,100,801	27.52
1889	5,938,635	21.04	1904	1,649,299	41.23
1899	10,097,893	34.22	1909	2,100,978	52.52
1909	18,675,376	63.29	1914	2,706,553	67.66
1919	29,504,792	100.00	1920	4,000,000 ¶	100.00
1925	41,000,000 §	139.00			
1930	51,000,000	173.00			
1940	75,000,000	254.00			
1950	100,000,000	339.00			
1960	130,000,000	441.00			
1970	158,000,000	536.00			
1975	170,000,000	576.00			

* Stat. Abs. of U. S., 1923, p. 800.

† G. F. Warren, Bul. 416, Agr. Exp. Sta., Cornell Univ., Ithica, N. Y., Jan., 1923. (Prices for 1900-1914, inc., are taken as 100.)

‡ Abs. of the Census of Manufactures, 1914, p. 491, Stat. Abs. U. S., 1923, p. 290.

§ Estimated trend, 1925-75.

¶ Approximately.

|| Census of Mfrs., 1914, p. 498.

TOTAL AUTOMOTIVE ENGINES

(Includes Passenger Cars, Motor Trucks, Motorcycles, Aeroplanes and Motor Boats.)

PLATE III CURVE 2

This curve represents a composite of five different estimates, as follows:

1. Passenger auto curve.
2. Motor truck curve.
3. $\left\{ \begin{array}{l} \text{Motorcycle curve.} \\ \text{Aeroplane curve.} \\ \text{Motor boat curve.} \end{array} \right.$

Tractors and stationary engines have been taken care of under the estimate made for the industrial use of motor fuel gradually converting to use of a fuel of heavier grade.

PASSENGER AUTOMOBILES

PLATES II AND III CURVE 2-A

This curve is based on the population curve and the "number of persons per car." This prediction agrees closely with figures compiled by the University of Maryland up to 1930 ("Elements Governing the Development of Highway Traffic," A. N. Johnson, Dean Eng. Coll. Univ. of Maryland. Appendix B, page 77).

The estimates of the increase in passenger car registration are based on the "Law of Growth," described by Raymond B. Prescott in "Automotive Industries," which may be stated in brief, as follows:

Growth of population as well as its economic activities, i.e., farming and *industry*, seem to follow a defined growth which passes through four stages in the course of its progress:

- (1) Period of experimentation,
- (2) Period of growth into social fabric,
- (3) Period of diminishing rate of increase, and
- (4) Period of stability.

A curve of passenger car registration was plotted from the beginning of record to the present. This curve was continued upward in reverse until it became tangent (1938) to the curve representing the number of families in the United States.

From this point, 1938, the curve of estimated passenger car registrations is obtained by dividing the population figure by 4. This assumed saturation ratio for the passenger automobile is assumed to be one to four persons, which, according to present statistics, agrees closely with the average census family.* This ratio of 1 to 4 also corresponds to the percentage of male white natives between the ages of 21 and 65, and to percentage of wage earners in the automobile owning class according to income and occupation.

MOTOR TRUCKS

PLATES II AND III CURVE 2-B

This estimate has been based both on population growth and industrial growth, and shows a faster increase in this type of vehicle than occurred in the passenger cars. This conforms to the estimated trend of industry in general in the United States.

Registration was plotted from beginning of record (1895) to 1923, from "Facts and Figures of the Automotive Industry for 1924" by National Automobile Chamber of Commerce.

AEROPLANES

PLATE III CURVE 2-C

Figures from the Department of Commerce show 662 aeroplanes in service in 1920 and 1500 in 1923. During the "experimentation stage" it was estimated that an increase would continue along present tendencies until 1930, after which the increase will be more rapid during the "period of growth," ending about the year 1950. After the year 1950, this growth follows the industrial growth curve. (Appendix D, page 238).

* Statistical Abstract of United States, 1923, 1920, 1910, etc.

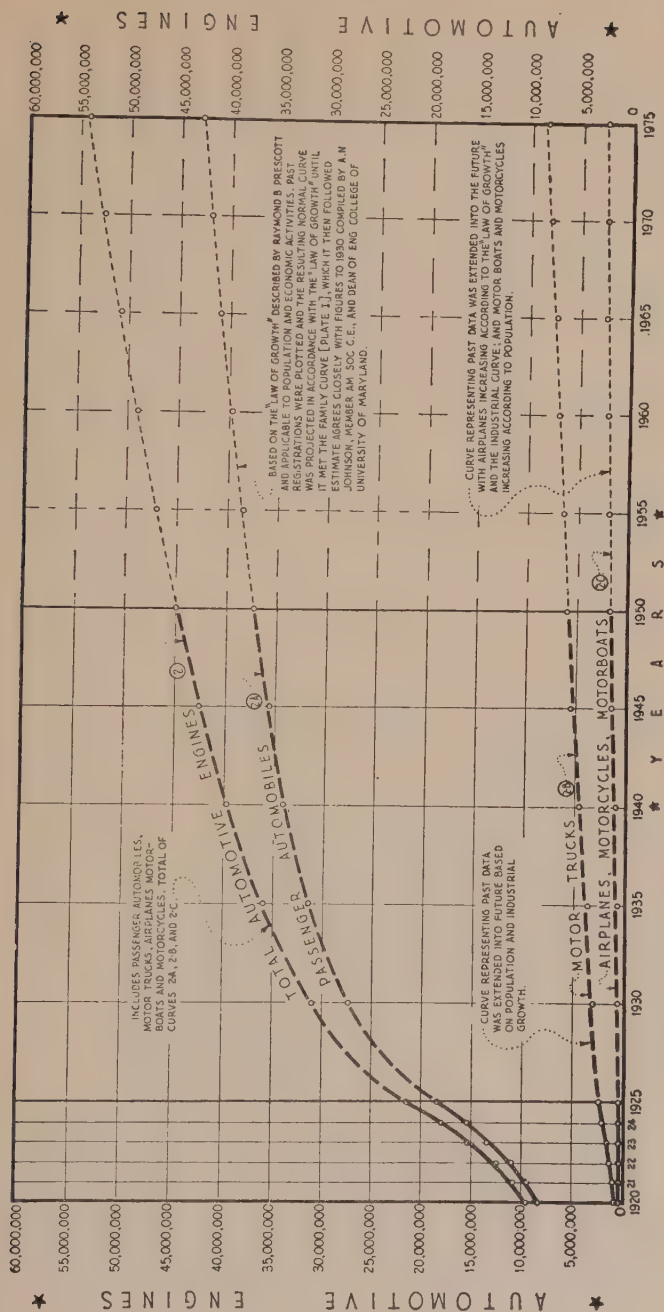


PLATE III.—ESTIMATED FUTURE AUTOMOTIVE ENGINES IN THE UNITED STATES.

MOTOR BOATS

PLATE III CURVE 2-C

On page 34 of the Petroleum Yearbook for 1922, the number of motor boats in use in 1920 was reported as 200,000. A curve starting at this figure was projected into the future to a point of saturation of about one to every seventy families by 1935, after which they increase according to population.

MOTORCYCLES

PLATE III CURVE 2-C

The number of motorcycles in service in the United States for 1924 was 153,900 and this was projected into the future with the population curve as a basis for determining the trend. (See Appendix E, page 239.)

TABLE III.—ESTIMATED FUTURE AUTOMOTIVE ENGINES
IN THE UNITED STATES

(Plate III)

Year	Total Automotive Engines (Curve 2)	Passenger Automobiles (Curve 2-A)	Motor Trucks (Curve 2-B)	Aeroplanes, Motorcycles, Motor Boats (Curve 2-C)
1920	9,672,000	8,380,000	852,000	440,000
1921	10,880,000	9,483,000	980,000	417,000
1922	12,663,000	10,960,000	1,279,000	424,000
1923	15,526,000	13,540,000	1,553,000	433,000
1924	18,028,000	15,461,000	2,131,000	436,000
1925	21,381,000	18,400,000	2,500,000	481,000
1930	31,018,000	27,400,000	3,000,000	618,000
1935	36,020,000	31,500,000	3,800,000	720,000
1940	39,755,000	34,080,000	4,700,000	975,000
1945	42,608,000	35,678,000	5,500,000	1,430,000
1950	44,990,000	37,170,000	6,000,000	1,820,000
1955	47,003,000	38,525,000	6,500,000	1,978,000
1960	48,984,000	39,808,000	7,000,000	2,176,000
1965	50,808,000	40,975,000	7,500,000	2,333,000
1970	52,461,000	41,986,000	8,000,000	2,475,000
1975	54,060,000	42,913,000	8,500,000	2,647,000

MAXIMUM GASOLINE OR EQUIVALENT DEMAND

PLATE IV CURVE 3

This curve represents the motor fuel demand in 42-gallon barrels, and is obtained by multiplying 10.1 barrels by the figure which represents total automotive engines, adding to this the gasoline required for industrial use. The average consumption per motor per year for the past seven years is 10.1 barrels and the assumption is made that while engines such as motorcycles and motor boats may use less than the average, aeroplanes and trucks will use more, hence the final figures will largely compensate each other.

GASOLINE CONSUMPTION PER AUTOMOTIVE ENGINE PER YEAR (1918-24)

(In 42-Gal. Barrels)

Date	Total Domestic Consumption of Gasoline in the U. S. *	Industrial Consumption of Gasoline †	Automotive Consumption of Gasoline *†	Automotive Engines ‡	Consumption per Automotive Engine per Year
1918	74,506,000	2,277,000	72,229,000	6,488,300	11.13
1919	81,781,000	2,289,000	79,492,000	7,957,500	9.99
1920	101,207,000	2,344,000	98,863,000	9,671,700	10.22
1921	107,488,000	2,321,000	105,167,000	10,879,900	9.67
1922	127,907,000	2,300,000	125,607,000	12,663,100	9.92
1923	159,172,000	2,291,000	156,881,000	15,525,500	10.10
1924	185,281,000	2,284,000	182,997,000	18,027,900	10.15
			821,236,000	81,213,900	10.1
					Weighted Average

* Figures from A. P. I. Bulletin, Vol. VI, No. 20, April 3, 1925.

† Estimated from data given by the Bureau of Census on p. 290 of the Statistical Abstract for 1923.

‡ Dept. of Commerce figures. See Table III.

MINIMUM GASOLINE OR EQUIVALENT DEMAND

PLATE IV CURVE 4

The minimum gasoline or equivalent demand is taken as one-half the maximum, based on double the present efficiency of motors, and an increase of 50% in efficiency for industrial use.

A claim of 100% increase in automotive efficiency seems justified by the statement of H. L. Horning, representing the Society of Automotive Engineers, before the American Petroleum Institute in December, 1923, which follows:

It is possible to double the miles per gallon of gasoline for cars and trucks. When the public wants it they can go 40 miles per gallon on small cars.

Further justification will be found in the remarks of C. F. Kettering, President, General Motors Research Corporation (see Appendix C, page 236).

In the more level areas in the United States, it is possible that engines will be used which will perform as economically as those used in England (Correspondence between R. W. Hanna and R. A. Halloran on "Automobile Efficiencies" September 23, 1924).

TOTAL MAXIMUM LUBRICATING OIL DEMAND

PLATE V CURVE 5

This curve represents the combined demand of automotive engines and industries. The detail regarding its construction follows:

LUBRICATING OIL DEMAND FOR AUTOMOTIVE ENGINES

PLATE V CURVE 5-A

This estimate was obtained by multiplying the average lubricating oil consumption per motor per year ($\frac{3}{4}$ barrel or 25 gallons) by a figure representing the estimated automotive engines (Table III, page 198). The average consumption of 25 gallons approximately checks with the figures published by J. H. Struth in "Oil Trade" May, 1925.

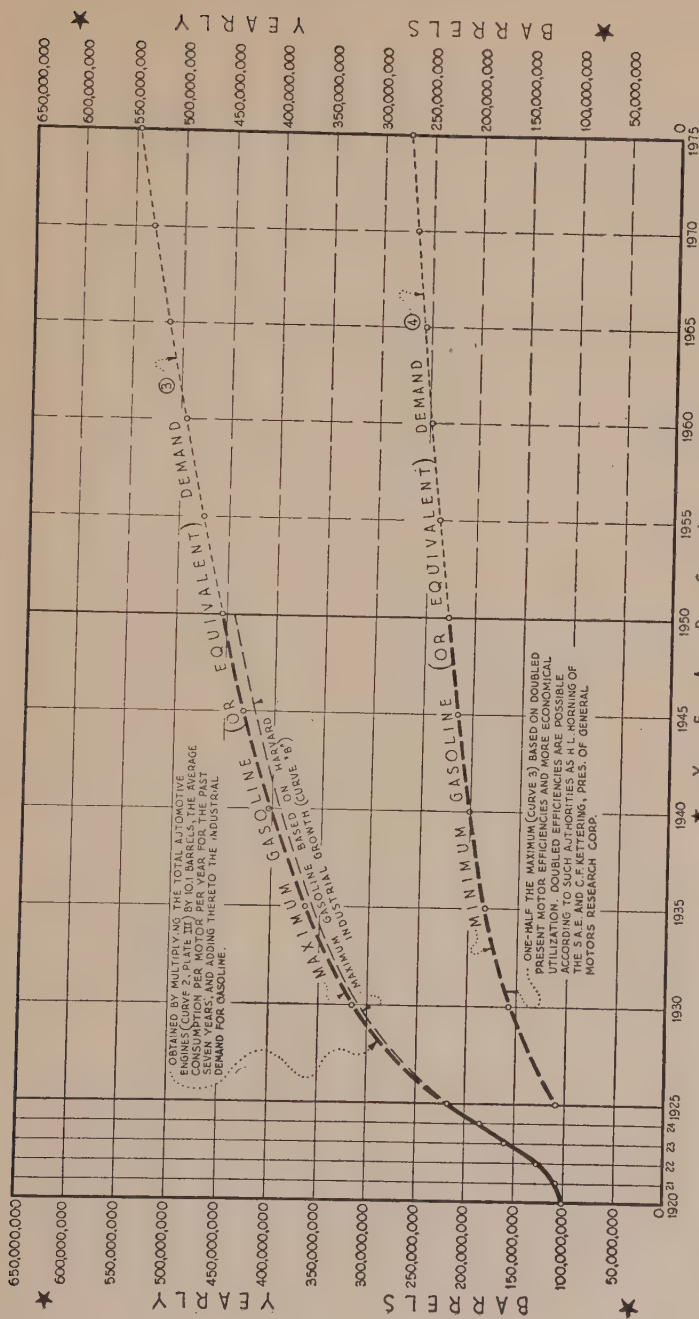


PLATE IV.—ESTIMATED FUTURE GASOLINE DEMAND IN THE UNITED STATES IN BARRELS OF FORTY-TWO (42) GALLONS EACH.

TABLE IV.—ESTIMATED FUTURE GASOLINE DEMAND*
IN THE UNITED STATES

(Plate IV)

Year	Maximum Gasoline Demand (Curve 3)	Minimum Gasoline Demand (Curve 4)
1920	101,207,000	
1921	107,488,000	
1922	127,907,000	
1923	159,172,000	
1924	185,281,000	
1925	218,215,000	109,107,000
1930	315,444,000	157,722,000
1935	365,780,000	182,890,000
1940	403,044,000	201,522,000
1945	431,560,000	215,780,000
1950	455,549,000	227,774,000
1955	475,880,000	237,940,000
1960	495,888,000	247,944,000
1965	514,311,000	257,155,000
1970	531,006,000	265,503,000
1975	547,156,000	273,578,000

* In barrels of 42 gals.

LUBRICATING OIL DEMAND FOR INDUSTRIES

PLATE V CURVE 5-B

The basic figure in this curve is 7,200,000 barrels, the industrial demand in 1924. This figure is obtained by deducting the motor vehicle demand from the Bureau of Mines domestic consumption figures for 1924. Future estimates are based on the estimated increase in industrial growth.

MINIMUM LUBRICATING OIL DEMAND

PLATE V CURVE 6

This curve represents 50% of the maximum demand,

(curve No. 5) and is the estimated future requirements based on:

- (a) Reclaiming used oil.
- (b) Improved and " oil-less " bearings.
- (c) Graphite mixtures.
- (d) More economy in use of lubricants.

(See Appendix F, page 240.)

TABLE V.—ESTIMATED FUTURE LUBRICATING OIL DEMAND*
IN THE UNITED STATES

(Plate V)

Year	Maximum Lubricating Oil Demand (Curve 5)	Maximum Automotive Lubricating Oil Demand (Curve 5-A)	Maximum Industrial Lubricating Oil Demand (Curve 5-B)	Minimum Lubricating Oil Demand (Curve 6)
1920	14,726,000	5,803,000	8,923,000	
1921	12,625,000	6,528,000	6,097,000	
1922	14,955,000	7,598,000	7,357,000	
1923	17,618,000	9,315,000	8,303,000	
1924	18,011,000	10,817,000	7,194,000	
1925	20,428,000	12,828,000	7,600,000	10,214,000
1930	28,311,000	18,611,000	9,700,000	14,155,000
1935	33,612,000	21,612,000	12,000,000	16,806,000
1940	38,653,000	23,853,000	14,800,000	19,326,000
1945	43,365,000	25,565,000	17,800,000	21,682,000
1950	47,994,000	26,994,000	21,000,000	23,997,000
1955	52,202,000	28,202,000	24,000,000	26,101,000
1960	56,590,000	29,390,000	27,200,000	28,295,000
1965	60,584,000	30,484,000	30,100,000	30,292,000
1970	64,477,000	31,477,000	33,000,000	32,238,000
1975	68,436,000	32,436,000	36,000,000	34,218,000

* In barrels of 42 gals.

MAXIMUM CRUDE DEMAND FOR MAXIMUM GASOLINE AND LUBRICATING OIL REQUIREMENTS

PLATE VI CURVE 7

This curve represents the crude needed to supply the maximum lubricating oil demand on a 25% yield of lubricants (see Appendix G, page 241) and a 33% yield of gasoline, (from Bureau of Mines statistics for year 1924), plus the additional crude needed to supply the remaining maximum gasoline demand on a 33% yield—plus the crude used for manufacturing in the refineries, which was taken as 5% of total run. The refinery requirement is taken as representing 97.1% of the crude production. An additional 1% is used by the operator in the field to produce the oil (U.S.G.S. report for December, 1924) leaving 1.9%, a part of which is considered as a loss and the remainder used as fuel in transporting the oil from the field to the refinery (See Appendix H, page 242). The result finally obtained represents the crude that would have to be *produced* to satisfy the estimated requirements.

MINIMUM CRUDE DEMAND FOR MINIMUM GASOLINE AND LUBRICATING OIL REQUIREMENTS

PLATE VI CURVE 8

This curve represents the crude needed to supply a minimum lubricating demand on a 25% yield of lubricants (see Appendix G, page 241) and a 33% yield of gasoline, plus the additional crude needed to supply the remaining minimum gasoline demand on a 55% yield (see Appendix I, page 244) plus the crude used for manufacturing in the refineries which was taken as 5% of a total run. As in the previous instance, this amount is taken as 97.1% of the crude production. An additional 2.9% is included to take care of production and transportation.

The significance of the crude curves is in pointing out

that under present practice the demand for lubricating oil and gasoline from crude would undoubtedly assume proportions out of line with the supply in a few years. Under conditions approaching maximum yields and increased efficiency in utilization, the demand on the crude supply for lubricants and gasoline can be brought within reasonable limits. It is expected that price increase due to the shortage of a natural supply will have the effect of prolonging the life of present reserves by allowing the economic consideration of substitutes and making it desirable to utilize the natural supply more efficiently.

TABLE VI.—ESTIMATED FUTURE CRUDE OIL DEMAND* TO SUPPLY ESTIMATED REQUIREMENTS OF GASOLINE AND LUBRICATING OIL IN THE UNITED STATES

(Plate VI)

Year	Maximum Crude Demand (Curve 7)	Minimum Crude Demand (Curve 8)
1920	446,859,000	
1921	456,643,000	
1922	515,654,000	
1923	554,377,000	
1924	615,860,000	
1925	716,849,000	232,771,000
1930	1,036,253,000	335,427,000
1935	1,201,609,000	389,633,000
1940	1,324,023,000	430,729,000
1945	1,417,699,000	462,919,000
1950	1,496,506,000	490,574,000
1955	1,563,293,000	514,261,000
1960	1,629,020,000	537,786,000
1965	1,689,542,000	559,405,000
1970	1,744,385,000	579,234,000
1975	1,797,439,000	598,583,000

* In barrels of 42 gals.

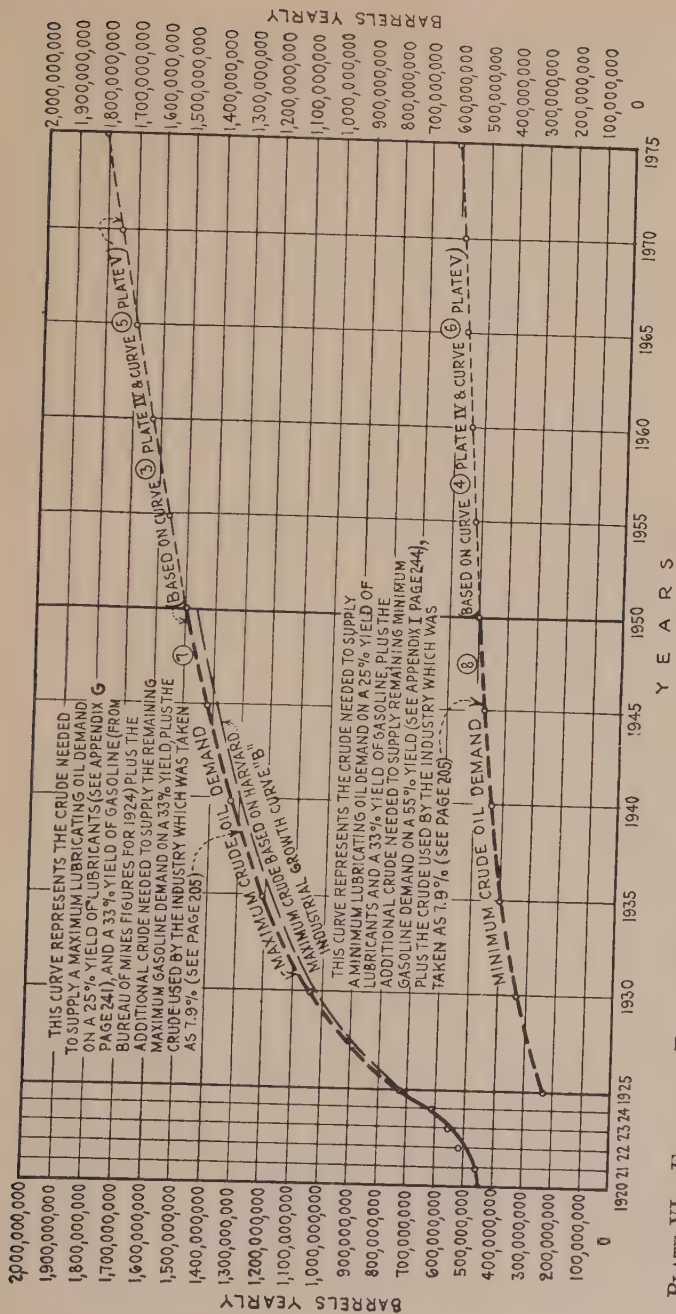


PLATE VI — ESTIMATED FUTURE CRUDE OIL DEMAND TO SUPPLY ESTIMATED REQUIREMENTS OF GASOLINE AND LUBRICATING OIL IN THE UNITED STATES.

FUTURE ESTIMATED ENERGY DEMAND IN THE UNITED STATES

PLATE VII CURVE 9

This curve represents a composite of seven different estimates, as shown below, covering the original sources of power as used in the United States. The energy derived from natural gas and wood is so insignificant at present that they have been included with fuel oil and coal respectively. The demand for power has been converted into a common unit—horse-power hours—to show the proportion of energy derived from each source. The equivalents used throughout these calculations are based on actual work delivered from fuel consumed, or energy developed, and include mechanical efficiencies as well as heat values. Where the energy required is in the form of direct heat, as for blast furnaces, any conversion to horse-power hours must necessarily be purely arbitrary.

(a) Automotive engine requirements—this estimate is based on figures obtained from calculating the maximum demand for gasoline or equivalent, for automobiles, trucks, aeroplanes, motor boats and motorcycles. (Plate IV, Curve 3.)

(b) Merchant marine requirements—this estimate is based on the present normal increase in gross tonnage of the American Merchant Marine. (Plate No. II.) The total energy required for the Merchant Marine (Fuel oil, 31,692,201 barrels; Diesel oil, 254,800 barrels; Coal, 4,614,632 tons in 1922—see Appendix J, page 245), was distributed in proportion to the energy supplied by each (63% fuel oil, 1% Diesel oil and 36% coal). Due to the increased price of fuel oil, it was estimated that the energy required for coal-burning vessels would remain constant until replaced by Diesel-driven ships, which would be about 1965, while fuel oil burning vessels would be replaced by Diesel-driven equipment at a rate of about 2% per year, the present tendency (57% of shipping under construction to be Diesel equipped—this tonnage representing 2% of the present tonnage afloat—see Appendix K, page 246). This would result in complete

replacement of oil-burning equipment by 1960, and complete Diesel driven Merchant Marine by 1965. Substitution of other Diesel engine fuels in place of petroleum has not been considered in these estimates.

(c) U. S. Navy requirements—The present Navy consumption (6,000,000 barrels fuel oil; 80,000 barrels Diesel oil, and 400,000 tons coal—see Appendix L, page 247) has been slightly increased to 1930, and then carried at a constant figure for the balance of the period, it being assumed that any additional increase in energy required would be automatically taken care of by increased efficiencies and conversion to Diesel equipment. The same rate of development of Diesel equipment was estimated for the Navy, as for the Merchant Marine, resulting in complete conversion by 1965.

(d) Public Utility Electric Plant requirements—The electricity generated by Public Utility Electric Plants was plotted for previous years, and divided into electricity for (1) power, and (2) for domestic purposes (see Appendix M, page 248). The power electricity was increased according to present trend of development, gradually conforming to the rate of industrial growth about 1950, after which date it increases with industries. In estimating the future domestic consumption of electrical energy, the growth of the number of consumers as given in the Statistical Abstract (see Appendix M, page 248) was extended and gradually reduced to conform to the growth of the number of families (one-fourth of the population) by about 1940. The amount of energy required per consumer was increased from the present value (see Appendix M, page 248) to about 3,800 horse-power hours per consumer per year by 1975. The figure 3,800 as a limit was arrived at by estimating roughly the amount of electricity required for a completely electrified home, heated, lighted and furnished with all the present electric auxiliaries, and assuming that 10% of the population were to live in such houses, and that half of the remainder would have houses completely equipped but not heated by

electricity, while the remainder would have houses lighted as at present.

The electrical energy thus required for power and domestic use was then totaled, to represent the anticipated energy required for public utility electric plants. The energy generated in these plants by fuel and water power for the past four years (see Appendix M, page 248) was plotted and the 1924 total fifty-eight billion, nine hundred ninety-six million (58,996,000,000) kilowatt hours extended along these lines to determine the energy to be required for the plants in the future. These requirements were divided into the original sources of power in the proportion obtaining in 1924 twenty billion, five million (20,005,000,000) kilowatt hours by water power and thirty-eight billion, nine hundred ninety-one million (38,991,000,000) kilowatt hours by fuels—see Appendix N, page 249), and the fuel energy distributed between coal and fuel oil in their relative proportions for that year (coal 90% and oil 10%—see Appendix N, page 249) it being assumed that the gas fuel used was largely manufactured from coal or oil, and the wood used, too small to consider separately.

The forecast for hydro-electric power was based upon figures taken from the U.S.G.S. Report dated April 29, 1924—(See Appendix O, page 250) which shows a total available supply of 55,000,000 horse-power at 50% efficiency or 35,000,000 at 90%. In predicting the rate at which this potential power will be developed, three general periods were considered, distinguished by the shifting of dominant control from one set of influences to another.

During the first period from 1900 to 1925, our development, which reached about 10,000,000 horse-power, was very slow compared to Canada, Norway, Japan and other countries, on account of:

1. Low price of fuel.
2. Remoteness of water power from great industrial centers, and lack of nationwide power transmission network.

3. Difficulty in financing projects, largely because of difficulty in obtaining satisfactory power site concessions from the Government.

During the second period, from 1925 to about 1950, we may expect to attain our maximum rate of development, as a result of:

1. Fuel becoming more expensive.
2. Growth of industries in water-power regions and development of nationwide transmission network.
3. Easier financing, resulting largely from the work of the Federal Power Commission in providing satisfactory concessions.

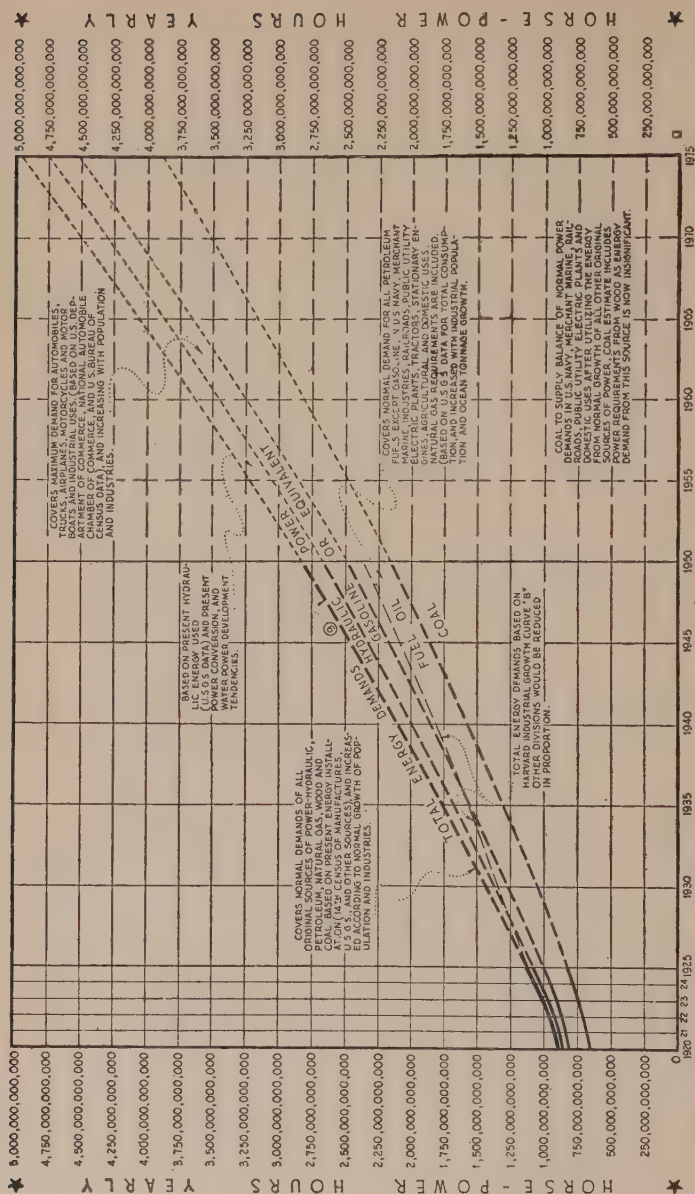
This period should see our developed power increase from 10,000,000 to perhaps 38,000,000, through the utilization of vast power sources which do not require unusually extensive storage projects.

During the third period, following 1950, our rate of development may be expected to decline markedly as the last feasible projects are launched, owing to the increasing extent and cost of the necessary storage facilities.

(NOTE.—If we accept the estimate published in the U.S.G.S. Water Supply Paper No. 234, 1908, of over 200,000,000 horse-power ultimately available by complete storage projects, our figures during the third period must be tripled. We have considered, however, that the 1924 report is the more reliable of the two.)

Hydraulic power has been divided between public utility electric plants and industries in proportion to present installed capacities (public utility plants, 7,348,197 horse-power and manufacturing plants, 1,738,761 horse-power—See Appendix O, page 250) and each division increased at the same rate of development, in accordance with the above outline, until the maximum potential hydraulic power was reached.

The remaining energy required for public utility electric plants is to be supplied from oil and coal (10% oil, and 90%



NOTE: Values for coal and total energy may be read directly from the scale but values for other power sources are proportional to the vertical distance between the curves.

PLATE VII.—ESTIMATED FUTURE ENERGY DEMANDS IN THE UNITED STATES.

coal, see Appendix N, page 249) with Diesel equipment entirely eliminating the use of fuel oil for steam generation by about 1950. Eventually, coal should be consumed near the mines in generating power, thus eliminating expensive costs in transportation of fuel.

(e) Railroad requirements—This is based on the present energy consumption per passenger-train-mile and freight-ton-mile, increasing each year in proportion to the population Curve and industrial growth. The freight-ton-mile prediction was subsequently found to check almost exactly with the forecast to 1945 made by J. B. Blood, Valuation Analyst of the Interstate Commerce Commission (Railway Age—Feb., 1924). From the standpoint of energy required, railroads have been divided into coal-burning, oil-burning and electric-driven.

At present, it is estimated that 15% of the railroads in the United States are electric, and that this electrification will increase at an average rate of about $3\frac{1}{2}\%$ per year, resulting in complete electrification of all railroads by about 1975. Due to possible remoteness of the majority of the railroads from natural hydraulic resources, it has been estimated that the energy required to generate this power will be supplied by oil and coal, assuming the same relationship for these two fuels as obtains at present in public utility electric plants (10% fuel oil and 90% coal—see Appendix N, page 249), and that all oil fuel will be used in Diesel equipment by about 1945.

The energy required for steam locomotives (139,275,000 tons coal; 244,144 cords wood; 45,944,548 barrels fuel oil in 1920. See Appendix P, page 251) has been taken in its present proportions (oil, 9%; coal, 91%—(see Appendix P, page 251) retaining this relationship until replaced by electric locomotives about 1975.

(f) Industrial requirements—This estimate has been based on the industrial growth curve, increasing present requirements (219,747,867 tons coal, 43,561,633 tons coke, 344,570,711 M. cubic feet gas, 2,344,469 barrels gasoline,

90,299,597 barrels fuel oil, 2,311,589 barrels Diesel oil and 19% of total developed water power in 1919—(see Appendix Q, page 252), according to this curve and then distributing the estimated requirements among the various sources of energy, the gas requirements being taken care of by fuel oil and coal, on the assumption that practically all the gas used was manufactured.

Hydraulic power has been increased at the same rate for industrial use as for public utility electric plants, and the balance of industrial energy taken care of by fuel oil and coal, 90% of fuel oil equipment converting to Diesel equipment by about 1975, the remaining 10% being considered as non-convertible. Coal retains its present relationship to oil fuel (coal, 92%; oil, 8%—see Appendix Q, page 252), throughout the period covered.

It has been assumed that the fuels used in stationary engines and tractors are taken care of in the gasoline, Diesel oil and fuel oil considered in this division of energy demand.

(g) Domestic and other requirements—From the total coal, fuel oil, gas oil, crude oil used as fuel, and natural gas consumption figures for the United States in 1920 (524,180,800 tons coal; 274,000,000 barrels fuel oil, gas oil and crude oil used as fuel; seven hundred ninety-eight billion, two hundred ten million (798,210,000,000) cubic feet natural gas—See Appendix R, page 253), have been deducted the amounts used in the Merchant Marine, U. S. Navy, public utility electric plants, railroads and industries, and it is assumed that the balance (approximately 48,900,286 tons coal, 86,042,779 barrels fuel oil, gas oil and crude used as fuel, and seven hundred ninety-eight billion, two hundred ten million (798,210,000,000) cubic feet natural gas), has been used for domestic and other purposes. Half of this remaining energy has been increased according to the population curve to take care of the domestic consumption, and the remaining half has been increased according to the industrial curve as the other uses for energy are probably distributed among the various industries.

These two estimates have been totaled to represent the energy required for domestic and other uses, segregating this energy into fuel oil and coal, retaining their present relationship throughout the period.

(h) From the foregoing estimates, the various sources of power have been totaled to determine the proportion of energy to be supplied by each and a smooth curve has been produced, showing the approximate relationship of each original source of energy to the estimated total energy demand of the United States.

Throughout these calculations, the following equivalents have been used, taking into consideration the heat values of the various sources of power, the average present efficiencies obtained, and the estimated increase in efficiency for the future.

CONVERSION FACTORS—1000 H.P. HOURS

	Minimum Efficiency	Maximum Efficiency
Gasoline (42-gal. barrel).....	2.3 bbl. throughout the period	
Diesel oil (42-gal. barrel):		
Ocean transportation.....	1.3 bbl. throughout the period	
Electric plants.....	1.2 bbl. in 1920	1.1 bbl. in 1975
Industries.....	1.2 bbl. in 1920	1.15 bbl. in 1975
Fuel oil (42-gal. barrel):		
Ocean transportation.....	3.1 bbl. in 1920	2.7 bbl. in 1960
Electric plants.....	3.4 bbl. in 1920	2.75 bbl. in 1945
Railroads.....	6.8 bbl. in 1920	2.3 bbl. in 1970
Industries and domestic....	2.48 bbl. in 1920	1.95 bbl. in 1975
Natural gas.....	22 M. cu. ft. throughout the period	
Coal (2000 lb. ton):		
Ocean transportation.....	.775 ton in 1920	.663 ton in 1965
Electric plants.....	.85 ton in 1920	.525 ton in 1975
Railroads.....	1.7 tons in 1920	.55 ton in 1975
Industries and domestic....	.62 ton in 1920	.495 ton in 1975

FUEL OIL DEMAND CURVE

(Present Tendency with Gradual Conversion to Use of Diesel Equipment)

PLATE VIII

CURVE 10

The foundation for this curve has been determined from the following data for 1920 and 1922:

	1920	1922
Fuel Oil and Crude Oil Used as Fuel (42-gal. barrel):		
Merchant Marine (see Appendix J, p. 245)..	26,334,883	31,692,201
U. S. Navy (see Appendix L, p. 247).....	6,714,000	6,000,000
Railroads (see Appendix P, p. 251).....	45,944,548	43,526,786
Public Utility Electric Plants (see Appendix M, p. 248).....	13,122,704	13,197,216
Industries (see Appendix Q, p. 252).....	90,299,597	104,601,440
Domestic and other Uses (estimated).....	88,851,179	121,128,757
Total fuel oil and crude used as fuel. . . .	271,266,911	320,146,400
Diesel Oil (42-gal. barrel):		
Merchant Marine (estimated).....	253,500	254,800
Electric Railroads (estimated).....	168,000	172,584
Public Utility Plants (estimated).....	.....	786,216
Industries (see Appendix Q, p. 252).....	2,311,589	2,640,000
Total Diesel oil used.....	2,733,089	3,853,600
Total fuel oil, gas oil and crude oil used as fuel (see Appendix R, p. 253).....	274,000,000	324,000,000

The Bureau of Mines data for total domestic consumption of fuel oil and gas oil indicate an increase each year from 1920 to 1924, but the amount of crude oil used as fuel during these years (U. S. G. S. data) has been variable, reaching a pronounced peak in 1923 with a marked decrease in 1924 (see Appendix S, page 254.) Assuming the sudden increase for 1923 to be of an abnormal character, the 1920 and 1922

figures have been used to determine a normal curve for the five-year period from 1920 to 1925, after which date the fuel oil demand has been based on the estimated energy demand for fuel oil (Plate VII) on the following basis:

From the Energy Demand Plate No. VII, the estimated horse-power hours to be supplied annually by fuel oil in the various branches of consumption, have been converted into barrels of fuel oil by using the conversion factors listed in connection with Curve No. 9 (page 212) and the total barrels of fuel oil plotted to produce a smooth curve indicating the barrels of fuel oil that will be required to supply the maximum energy demanded from this source of power, taking into consideration the present Diesel conversion tendency and possible normal replacement by hydraulic power and coal, as outlined in the discussion for Curve No. 9.

FUEL OIL DEMAND CURVE

(Abrupt Replacement of Fuel Oil by Other Fuels, Using Only 100% Ocean Transportation, and 5% Industrial Use.)

PLATE VIII CURVE 10-A

Assuming that, due to drastic conservation measures, an abrupt change will occur at once, converting all oil-burning equipment except the most essential into equipment using other sources of power, the estimated fuel oil demand as shown in Curve No. 10 has been taken as the basic curve, and the assumption made that all land use of fuel oil except 5% of the estimated industrial requirements will be immediately replaced by other sources of energy, the fuel oil estimate for ocean transportation being carried at 100% throughout the period.

After plotting the above estimate, minor modifications have been made to produce a smooth curve for the entire period.

FUEL OIL DEMAND CURVE

(American Merchant Marine and U. S. Navy Only)

PLATE VIII CURVE 10-B

This curve is based on the calculations for Curve No. 10, eliminating all estimated fuel oil requirements for land use, and using 100% of the estimated ocean transportation requirements throughout the period.

After plotting the above estimate, minor modifications have been made to produce a smooth curve, representing a possible minimum fuel oil demand.

TABLE VII.—ESTIMATED FUTURE FUEL OIL DEMAND *
IN THE UNITED STATES

(Plate VIII)

Year	Maximum Fuel Oil Demand (Curve 10)	Restricted Land Use, 100% Navy and Merchant Marine (Curve 10-A)	U. S. Navy and Merchant Marine (Curve 10-B)
1920	274,000,000		
1921	274,000,000		
1922	324,000,000		
1923	395,000,000		
1924	391,000,000 †		
1925	374,000,000	63,000,000	57,000,000
1930	455,000,000	75,000,000	67,000,000
1935	524,000,000	83,000,000	74,000,000
1940	573,000,000	86,000,000	75,000,000
1945	613,000,000	86,000,000	74,000,000
1950	641,000,000	83,000,000	71,000,000
1955	679,000,000	77,000,000	64,000,000
1960	726,000,000	70,000,000	56,000,000
1965	762,000,000	76,000,000	62,000,000
1970	816,000,000	81,000,000	66,000,000
1975	840,000,000	83,000,000	68,000,000

* In barrels of 42 gals.

† Preliminary.

TABLE VIII.—ESTIMATED YIELD, RESIDUUM AS POSSIBLE FUEL OIL TO BE DERIVED FROM FUTURE (THEORETICAL) RUNS OF CRUDE

(Minimum Demand)*

Year	From Run of Crude to Lubricating Oil	From Run of Crude to Gasoline	Total
1925	17,160,000	78,239,000	95,399,000
1930	23,780,000	113,758,000	137,538,000
1935	28,234,000	131,487,000	159,721,000
1940	32,468,000	144,010,000	176,478,000
1945	36,426,000	153,131,000	189,557,000
1950	40,315,000	160,444,000	200,759,000
1955	43,850,000	166,489,000	210,339,000
1960	47,536,000	172,305,000	219,841,000
1965	50,891,000	177,685,000	228,576,000
1970	54,160,000	182,413,000	236,573,000
1975	57,486,000	186,881,000	244,367,000

* In barrels or 42 gals. each.

ESTIMATED OIL SHALE RESERVES IN THE UNITED STATES FOR
MAXIMUM GASOLINE DEMAND OR EQUIVALENT

PLATE IX

Oil Shale.—The amount of oil shale available in the United States is estimated at about three hundred ninety-four billion (394,000,000,000) tons based on reports to the "Supply Group" of the "Committee of Eleven" of the American Petroleum Institute (see Appendix T, page 255). It is further estimated that this reserve of shale will yield approximately one hundred eight billion (108,000,000,000) barrels of oil or 11.5 gallons per ton.

Two curves are shown for oil shale, showing amounts available if the entire *maximum gasoline demand* of the country were to be supplied by the shale, assuming yields of:

- (a) Six gallons of gasoline per ton of shale (Curve No. 11)

(b) Three gallons of gasoline per ton of shale (Curve No. 12).

Should the present supply of motor fuel suddenly become exhausted it is found, on the basis of the above assumption, that were the maximum gasoline requirements to be supplied from oil shale, these reserves by 1975 would be reduced 78% by a three-gallon yield and about 39% by a six-gallon yield.

TABLE IX.—ESTIMATED RESERVES OF OIL SHALE IN THE UNITED STATES

(PLATE IX)

(Based on Recovery of 6 gals. Gasoline per Ton of Shale)

Period	Maximum Gasoline Consumption For Period *	Oil Shale Reserves Remaining at End of Period	
		Oil * (Curve 11)	Shale †
1920-1925	.....	108,000	394,000
1925-1930	1334	105,000	385,000
1930-1940	3658	98,000	359,000
1940-1950	4316	90,000	329,000
1950-1960	4759	81,000	295,000
1960-1970	5143	71,000	259,000
1970-1975	2695	66,000	241,000

(Based on Recovery of 3 Gals. Gasoline per Ton of Shale)

		(Curve 12)	
1920-1925	.....	108,000	394,000
1925-1930	1334	102,000	375,000
1930-1940	3658	88,000	324,000
1940-1950	4316	72,000	264,000
1950-1960	4759	54,000	197,000
1960-1970	5143	34,000	125,000
1970-1975	2695	24,000	87,000

* Oil and gasoline in millions of barrels of 42 gals.

† Shale in millions of tons.

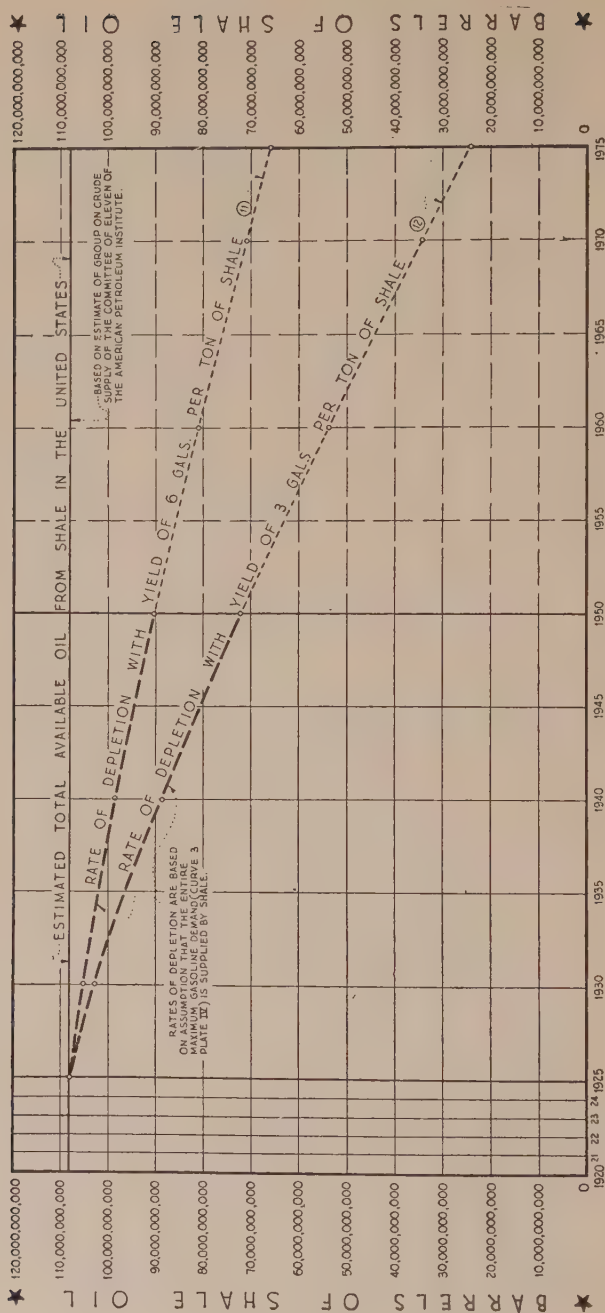


PLATE IX.—ESTIMATED RESERVES OF OIL SHALE IN THE UNITED STATES IN BARRELS OF 42 GALLONS EACH.

ESTIMATED RESERVES OF SOFT COAL AND LIGNITE IN THE UNITED STATES

(PLATE X)

Coal Demand, Present Tendency (Curve No. 13).

From the report of the "Supply Group" of the Committee of Eleven of the American Petroleum Institute (see Appendix U, page 256) figures are obtained showing the estimated reserves of soft coal and lignite to be four trillion, one hundred thirteen billion, eight hundred sixty million (4,113,860,000,000) tons. The oil or tar recoverable from this coal is estimated at five hundred ninety-five billion, five hundred million (595,500,000,000) barrels of 42 gallons, capable of yielding one hundred three billion, six hundred million (103,600,000,000) barrels of light motor fuel.

From Plate VII (Coal Demand) the amounts of coal used up to the end of each five- or ten-year period have been calculated, and subtracted from the original amount to give the curve marked "Present Tendency" (Curve No. 13).

Coal Demand, Present Tendency and Replacing Gas and Fuel Oil (Curve No. 14)

A further deduction has been made of the amounts of coal corresponding to the gas and fuel oil energy demand shown on Plate VII (Fuel Oil) to give the amounts of coal remaining if it should be necessary to use coal in place of the estimated maximum gas and fuel-oil requirements.

Coal Demand—to Supply all Fuel and Lubricating Oil Requirements, by Distillation (Curve No. 15)

This curve represents the remaining reserves after supplying all the coal that would be required to furnish gas, gasoline (benzol), fuel oil, lubricating oil and coal (coke) in sufficient quantities by distillation, to take care of the estimated maximum requirements for all of these fuels, as shown on Plate VII (Gasoline, Fuel Oil, and Coal Demands). This has been calculated on the following basis:

Gas.—It has been assumed that sufficient gas will be produced in the course of distillation for liquid fuels, to take care of the estimated gas requirements.

Gasoline.—The estimated maximum demand for gasoline has been supplied from the estimated recoverable light motor fuel from coal of one hundred three billion, six hundred million (103,600,000,000) barrels which is on the basis of 1.06 gallons per ton of coal and lignite (see Appendix U, page 256).

Diesel Oil, Fuel Oil, Lubricating Oil.—The total quantity of recoverable liquid products from the coal is estimated at five hundred ninety-five billion, five hundred million (595,500,000,000) barrels, an average of 6.08 gallons per ton (see Appendix U, page 256). From this amount 1.06 gallons per ton or 17.4% is taken as light motor fuel, and the remaining 82.6% of the liquid products is considered suitable for supplying the required Diesel oil, fuel oil and lubricating oils. The coal required to supply the maximum gasoline demand, would leave sufficient of the heavier oils to meet all estimated requirements for Diesel oil, fuel oil and lubricating oils, and leave a large surplus.

Coal.—It is estimated that from every ton of coal distilled there will be recovered an average of 1,100 pounds of coke. On account of the additional efficiency in the utilization of coke, it is assumed that 1,500 pounds of coke will perform the same amount of work as 2,000 pounds of coal. With these deductions, the necessary amount of coke to supply the estimated coal requirements (Plate X, Curve No. 13) has been calculated, resulting in a large surplus of coke when producing sufficient motor fuel to satisfy the estimated maximum demand.

While there are abundant reserves of coal in the United States, more than sufficient to supply all power demands of this country for the next fifty years by distillation, it is improbable that such practice will ever be universally

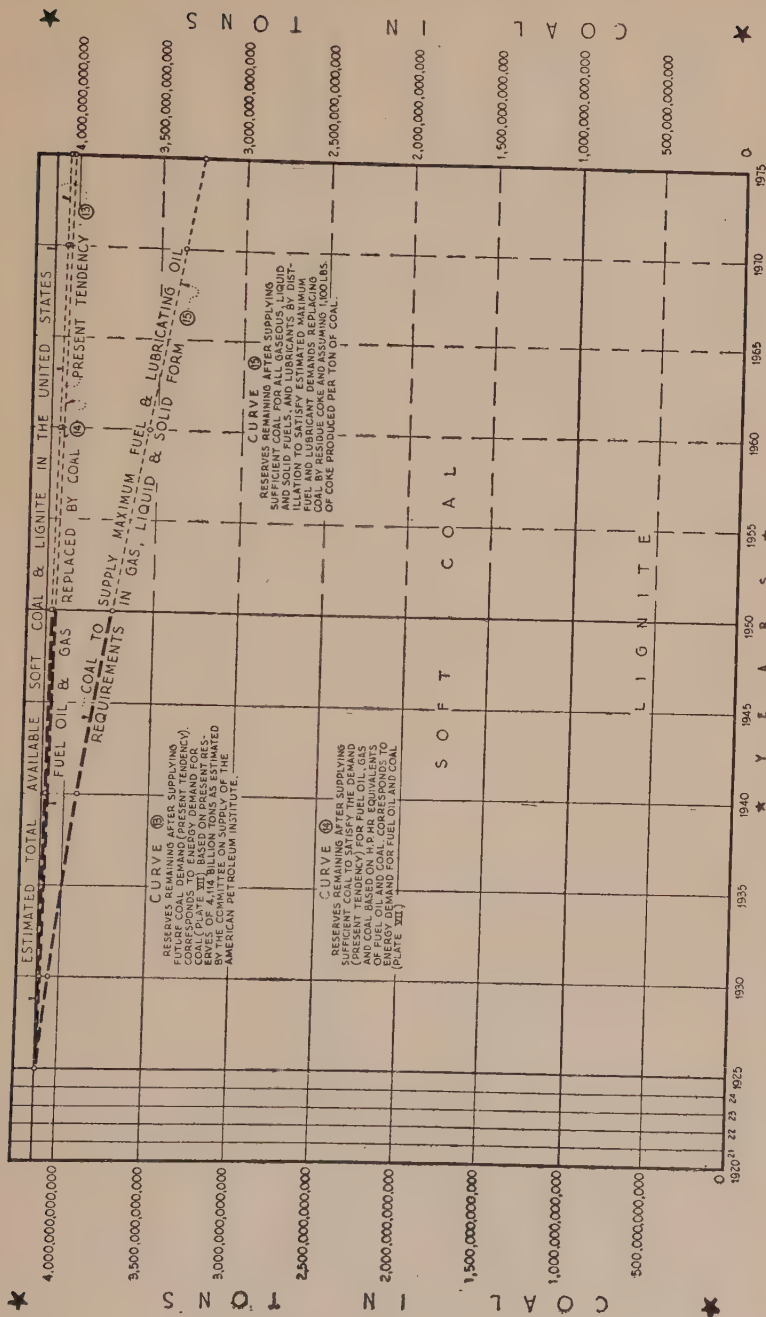


PLATE X.—ESTIMATED RESERVES OF SOFT COAL AND LIGNITE IN THE UNITED STATES.

adopted due to the excessive surplus of by-product coke and fuel oil that would have to be produced in supplying the required quantities of motor fuel.

However, it is probable that future developments in chemistry, possibly within the next decade, will result in the discovery of a process by which coal will be converted directly into motor fuel as a primary product, with valuable by-products (see Appendix V, page 258).

When this theory becomes fact, the practice of utilizing the vast coal reserves of the United States may become economically practicable, which should greatly augment the domestic supply of motor fuels.

TABLE X.—ESTIMATED RESERVES OF SOFT COAL AND LIGNITE *
IN THE UNITED STATES

(PLATE X)

Reserves Remaining at End of Period

Period	Supplying Coal Demand (Present Tendency) (Curve 13)	Supplying Coal Demand and Substituting for Fuel Oil and Gas (Curve 14)	Supplying All Fuels and Lubricating Oil by Distillation (Curve 15)
1920-1925	4,113,000	4,113,000	4,113,000
1925-1930	4,110,000	4,109,000	4,060,000
1930-1940	4,100,000	4,098,000	3,915,000
1940-1950	4,089,000	4,085,000	3,744,000
1950-1960	4,075,000	4,068,000	3,555,000
1960-1970	4,058,000	4,049,000	3,351,000
1970-1975	4,049,000	4,038,000	3,244,000

* In millions of tons.

XI—APPENDICES

APPENDIX A

INDUSTRIAL GROWTH INDEX DATA OF HARVARD ECONOMIC SERVICE *

* Being a copy of letter dated May 1, 1925, from the Harvard Economic Service to J. Edgar Pew.

CAMBRIDGE, MASSACHUSETTS,
May 1, 1925.

MR. J. EDGAR PEW, *President*,
American Petroleum Institute,
15 West 44th Street,
New York, N. Y.

DEAR SIR:

We have scrutinized in detail the report left with us by Mr. Wagy, and have examined the available data (which we believe reliable) which would bear upon a forecast of industrial activity. From our study of these data we have made an independent estimate of industrial activity during the twenty-five-year period, 1925-1950. In our opinion an estimate carried beyond 1950 requires a forecast of such a variety of technical factors that an economic statistician would not be justified in presenting figures for the years thereafter.

I

Data showing the growth of industrial activity in the United States during the past century appear in Table I. Figures are given at intervals of twenty-five years; in order to obtain a rough approximation to a normal figure, at each of the four dates (1825, 1850, 1875 and 1900) a five-year average centering at the date in question has been used rather than the actual figure for that year. In 1925 the estimated normal figures of the Harvard University Committee on Economic Research have been entered in the table.

TABLE I.—DATA SHOWING GROWTH OF INDUSTRIAL ACTIVITY
IN THE UNITED STATES, 1825-1925

Actual Figures

Average for the Five Years Centering at	Bituminous Coal Production (Unit: 1000 Net Tons)	Pig Iron Production (Unit: 1000 Gross Tons)	Volume of Manufacture (Base: 1899 = 100%)
1825	77		
1850	2,840		
1875	30,900	2,180	
1900	212,000	14,580	107
1925	583,000 *	36,700 *	276 *

Approximate Rate of Increase from Preceding Figure

Average for the Five Years Centering at	Bituminous Coal Production	Pig Iron Production	Volume of Manufacture
1825			
1850	37-fold		
1875	11-fold		
1900	7-fold	7-fold	
1925	2 $\frac{3}{4}$ -fold	2 $\frac{1}{2}$ -fold	2 $\frac{1}{2}$ -fold

* Estimated normal for 1925.

From Table I it is clear that there has been a "dampening" in the *rate of increase* of industrial activity during the past 100 years. Thus, bituminous coal production increased about 37-fold between 1825 and 1850, 11-fold between 1850 and 1875, 7-fold between 1875 and 1900, and only about 2 $\frac{3}{4}$ -fold between 1900 and 1925.

In view of the tendency disclosed by those figures it seems to us highly improbable that the rate of increase in the volume of manufacture which obtained over the period 1900 to 1925 (about $2\frac{1}{2}$ -fold) will also hold for the period 1925 to 1950. Rather is it to be expected that the "dampening" tendency in the rate of growth will continue. In our judgment it seems unlikely that the rate of growth will be more than 2-fold over the period 1925 to 1950; and our estimate of the *maximum rate of activity* in 1950 is promised upon the assumption that manufacturing output in 1950 will be not more than double that of 1925.

II

Table II shows estimates of normal indexes for manufacturing activity at five-year intervals, 1925 to 1950, on the assumption stated above (of a 2-fold increase between 1925 and 1950).

TABLE II.—INDEXES OF ESTIMATED NORMAL INDUSTRIAL ACTIVITY,
1925-1950

(Normal for 1925=100)

1925=100	1935=132	1945=174
1930=115	1940=152	1950=200

A more detailed set of figures for industrial activity, 1825 to 1925, appears in Table III below. Here again five-year averages centering at the dates indicated have been used, and the 1925 estimated normal figures of the Harvard University Committee on Economic Research have been entered for that year. Table III shows, in the form of five-year averages, for each of three series—bituminous coal production, pigiron production and total manufacture: (1) Actual figures; (2) Indexes (estimated normal for 1925=100); (3) Percentage which the Actual Figure for each Period Bears to the Actual Figure for the Preceding Period.

TABLE III.—DETAILED STATISTICS, 1825-1925

Average for Five Years Centering at	Bituminous Coal Production (Unit: 1000 Net Tons)	Pig Iron Production (Unit: 1000 Gross Tons)	Volume of Manu- facture (Base: 1899)	Bituminous Coal Production	Pig Iron Production	Volume of Manu- facture
1825	77	.....	.....	.013		
1830	115	.....	.....	.020		
1835	146	.....	.....	.025		
1840	891	.....	.....	.15		
1845	1,744	.....	.....	.30		
1850	2,840	.....	.....	.49		
1855	4,740	.....	.....	.81		
1860	6,510	712	.....	1.1	1.9	
1865	12,110	1,040	.....	2.1	2.8	
1870	20,800	1,812	.....	3.6	4.9	
1875	30,900	2,180	.....	5.3	6.0	
1880	47,900	3,530	.....	8.2	9.6	
1885	79,300	4,970	.....	14	14	
1890	110,800	8,150	.....	18	22	
1895	133,500	8,300	84	23	23	30
1900	212,000	14,580	107	36	40	39
1905	323,000	21,700	138	55	59	50
1910	397,000	24,500	154	68	67	56
1915	480,000	32,500	199	83	89	72
1920	490,000	29,800	216	84	81	78
1925	*583,000	*36,700	* 276	100	100	100

* Estimated normal for 1925.

TABLE III.—DETAILED STATISTICS, 1825-1925—*Continued*

Average for Five Years Centering at	Percentage which Actual Figure Bears to Preceding Actual Figure		
	Bituminous Coal Production	Pig Iron Production	Volume of Manufacture
1825			
1830	149		
1835	127		
1840	610		
1845	196		
1850	163		
1855	167		
1860	137		
1865	186	146	
1870	172	174	
1875	148	121	
1880	155	162	
1885	166	141	
1890	140	164	
1895	120	102	
1900	160	176	129
1905	152	149	129
1910	123	113	112
1915	121	132	129
1920	102	92	108
1925	119	123	128

In the making of this study we have been assisted by members of the staff of the Harvard University Committee on Economic Research, and especially by Mr. Edwin Frickey, Statistician, who is chiefly responsible for the technical operations of that staff.

Very truly yours,

W. L. CRUM

Assistant Professor of Statistics, Harvard University
Statistician, Harvard University Committee on
Economic Research

HOMER B. VANDERBLUE

Professor of Business Economics, Harvard University
Assistant Director, Harvard University Committee
on Economic Research

APPENDIX B

SATURATION POINT FOR AUTOMOBILES

JOHNSON, A. N.—Elements Governing the Development of Highway Traffic. Advance issue of paper for presentation at Jan. 22, 1925, meeting of Highway Div., A.S.C.E., New York City.

Discusses future traffic on American highways, with curves showing relation between motor vehicles and population in the United States. "It is difficult to imagine that an average of less than four persons per automobile will be reached." States that this point may likely be reached in 1928. Figures include all motor vehicles.

SLOAN, WM. G.—Probable future conditions of traffic. Journal Soc. Auto. Eng., September, 1924, page 239.

Presents a graph of relation between persons per automobile and date, by states. Predicts a saturation ratio of 1-4 for New Jersey about 1929 and states that curves for other states will flatten out at 1-4 ratio.

AYERS, LEONARD P.—The Automobile Industry and its Future.

(1) Pamphlet by Cleveland Trust Co., 1921, tables, and charts. 32 pages.

Develops theory of number of automobiles *in use*, based on registration and production. Deduces the life of average car. Discusses theoretical market for automobiles on three bases:

- (1) Number of white, native born men above 21 years of age.
 - (2) Number of white American families.
 - (3) Number of persons whose occupations make it appear possible that they might become motor car owners.
- Figures include trucks.

(2) Address to Soc. Auto. Eng., N. Y., Jan. 8, 1925, Journal Soc. Auto. Eng., February, 1925, page 195.

It seems probable that the number of automobiles that this country can use is not far from equal to the number of families, estimated potential market at 27,000,000 and estimated 1925 production of cars at 3,600,000.

SHIDLE, NORMAN, G., and PRESCOTT, R. B.—Statistics for use in making sales plans. *Auto. Ind.*, Nov. 17, 1921, pages 951–955.

A study of the growth of the automobile industry as related to growth of population. A “law of growth” is developed by mathematical analysis of statistical data and predictions made as to production and registration.

FACTS AND FIGURES OF THE AUTOMOBILE INDUSTRY.—National Auto. Chamber of Commerce, 366 Madison Ave., N. Y., 1924 Edition.

APPENDIX C

INCREASED EFFICIENCY OF FUEL FOR AUTOMOBILES

An excerpt from A Critical Analysis of the Future Demand for Gasoline and Lubricating Oils for Automotive Uses, by H. L. HORNING, *President*, Society of Automotive Engineers.

The miles per gallon for the country can be doubled within 15 years after price demands the change and much sooner for individual cases, product, or large, well-managed fleets.

With gasoline of Navy specifications made from Mid-Continent crude and without dope, it is possible to drive a sedan car of well known make with a weight of 3665 lbs., including two passengers, equipped with a high efficiency engine, at the rate of 25 miles per hour and make 36 miles per gallon. It is possible to drive the same car at 40 miles per hour and give 30 miles per gallon. It is possible to drive this same car with rich setting up to 60 miles per hour and make 30 miles per gallon at 30 miles per hour. The same car with its own engine makes from 16 miles per gallon at 30 miles per hour. I am therefore fully impressed with the statement that any time the price gets to a point which makes it an object for users to demand economy, it will be possible and practical to double the present mileages. I know it is possible to exceed this.

This engine has 150 cu. in. displacement. Placed in a well known light car it will exceed 40 miles per gallon. This car now averages 16 miles per gallon. There is then added testimony that doubling the mileage is possible and practical.

The difficulty with our engines and car combinations is known to be the low power factor or percentage of full load at which all cars operate. To prove this out I instituted experiments and my men drove the above mentioned car as follows: (1) With a 3.63—1 rear axle gear ratio we attained 37.2 miles per gallon. (2) With a 3-1 ratio we attained 41.2 miles per gallon.

To a query from R. L. Welch, General Secretary of the American Petroleum Institute, C. F. Kettering of the General Motors Research Corporation replied as follows:

We believe that it is possible to make automobiles go twice as far per gallon of gasoline used. The present internal combustion engine and automobile only transforms on an average of 5% of the energy originally in the

gasoline into useful work. It is possible at present to transform 10% of this energy into useful work, and this will be common practice in the future.

We feel that it is possible to-day, by correlating a number of things which are known in the modifications of fuels and in the design of motors, to almost double the transportation efficiency of a gallon of gas. This is a thing which cannot come suddenly, but which will be a development throughout a period of years. It is only a question of modifying designs of engines, which need not be radical.

APPENDIX D

AEROPLANES

Is the Automobile Industry Destined to Lead in Air Development? By JOHN C. GOURBI,

Automotive Industries, April 30, 1925, page 767.

APPENDIX E

MOTORCYCLES IN SERVICE IN U. S.

1920—239,000

1921—196,000

1922—183,000

1923—171,000

(From Commerce Year Book, 1923, page 351.)

1924—153,925

(Report of Bureau of Public Roads, U. S. Dept. of Agriculture.)

APPENDIX F

INCREASED EFFICIENCY OF LUBRICATING OIL FOR AUTOMOBILES

An excerpt from A Critical Analysis of the Future Demand for Gasoline and Lubricating Oils for Automotive Uses, by H. L. HORNING, *President*, Society of Automotive Engineers.

If the methods of burning gasoline are wasteful today the art of lubrication is primitive. This applies equally to refining of lubricating oil as well as its mechanical application. Our methods of lubrication are entering a new era.

Usually it is dangerous when possible at all to attempt to lubricate automotive engines at the rate of 2,500 miles per gallon. Today 1,000 miles per gallon is as many miles as can be safely attained without the great mechanical wear which occurs at 2,500 miles per gallon. Oil is lost, not used. I expect lubricating oil mileages to increase as follows:

1925, 100%;	1930, 125%;	1950, 225%
-------------	-------------	------------

APPENDIX G

References on 25% yield of lubricants from crude petroleum.

DAVID T. DAY, in "A Handbook of the Petroleum Industry,"
page 357.

BACON & HAMOR, in "American Petroleum Industry"—Vol. II,
page 474.

BUREAU OF MINES, in reports on "Properties of Typical Crude
Oils from the Producing Fields of the United States."

APPENDIX H

In order to ascertain the loss in volume of oil in field storage, in transportation from producer to refiner, in refineries, and in distribution and sales, inquiries were sent by the secretary of the American Petroleum Institute to a number of representative companies.

Responses were received from 16 companies relative to field storage, transportation, distribution and sales; and from 20 companies as to losses in refineries.

The responses cover approximately half of the oil handled by the industry in the year 1924.

The figures show a total loss in volume by the reporting companies of $3\frac{1}{3}\%$.

FIELD STORAGE AND TRANSPORTATION LOSSES FROM PRODUCER TO REFINER

All Figures Net Oil at 60 Less S. and W. (42-Gal. Barrels)

1. Stocks of crude oil on hand, Dec. 31, 1923, including producing and pipe line storage but not including crude oil at refinery.....	129,966,338
2. Stocks of crude oil on hand, Dec. 31, 1924, as above.....	131,793,168
3. Total deliveries of crude oil to refinery, or otherwise, during period Dec. 31, 1923, to Dec. 31, 1924.....	351,694,989
4. Barrels loss, to include evaporation and leakage, etc., but not to include losses incurred by fire, floods or other force majeure items.....	4,040,409
5. Per cent loss, based on total deliveries of crude oil to refinery, or otherwise.....	1.15

REFINERIES

All Figures Net at 60° Less S. and W. (42-Gal. Barrels)

1. Total oil run to stills.....	364,288,043
---------------------------------	-------------

In this item, include not only crude oil run, but any tops, distillates, or other petroleum products, brought into refinery from outside sources, and run through stills.

2. Per cent loss, based on total quantity run through stills. . . . 1.51

This should cover leakage, evaporation, filling, shipping and filtering losses and losses from stored oil. (It is assumed that still-vent gas is recovered and burned; that coke, if manufactured, is either burned or sold; that acid sludge is recovered and the tar burned or burned without recovery. If any of these are not used, show as a separate loss. This should not include losses incurred by fire, floods, or other force majeure items.)

SALES AND DISTRIBUTION

All Figures Used to be Net at 60° Less S. and W.

1. Per cent loss, based on volume of deliveries, covering leakage, evaporation, filling, and shipping, etc., but not to include losses incurred by fire, floods, or other force majeure items. $\frac{6.7}{100}$ of 1%*

*Arithmetical average.

APPENDIX I

References on 55% yield of Gasoline on Plate VI. Curves 7 and 8:

CHARLES E. BOWLES in "Industrial Significance of Cracking," in Oil and Gas Journal, 7/24/24.

ROY CROSS in "Properties of Typical Samples of California Petroleum," in Oil Age, Oct., 1924.

RATHBUN (Petroleum Age) in "Costs on Cross Process," in Rathbun's Oil Data—Leaflets.

FRANCIS HYNDMAN in "The Greenstreet Process of Cracking" in "Oil Engineering and Finance"—July 28, 1923.

PETROLEUM TIMES, 1/19/24, discussing "The Blummer Process."

APPENDIX J

MERCHANT MARINE REQUIREMENTS

BUNKER OIL FOR FOREIGN TRADE

1920	26,334,883 bbls.
1921	27,076,138 bbls.
1922	31,692,201 bbls.
1923	37,581,845 bbls.

(U. S. Bureau of Mines data. Statistical Abstract of U. S., 1923, p. 278.)

BUNKER COAL FOR FOREIGN TRADE

1920	9,362,178 long tons
1921	7,547,518 long tons
1922	4,120,207 long tons = 4,614,632 short tons
1923	4,547,343 long tons

(Statistical Abstract of U. S., 1923, page 273.)

DIESEL OIL

(Based on Gross Tonnage of Motorships in U. S.)

	Total Tonnage	Motorship Tonnage	Percentage
1922	15,808,462	188,283	1.2
1923	15,684,787	192,595	1.2
1924	14,771,314	248,234	1.7

(Data compiled by Marine Dept., Auditor's Division, Standard Oil Company (California), January 7, 1925.)

1.2% of Total Marine Energy for 1922 equals 196,489,000 H.P. Hr., or 254,800 bbls. Diesel oil.

APPENDIX K

GROWTH OF DIESEL EQUIPMENT IN MERCHANT MARINE

Fifty-seven per cent of vessels now in course of construction or contracted for throughout the world will be equipped with Diesel engines.—(S. F. Examiner, Dec. 2, 1924.)

Vessels under construction throughout the world as of Dec. 31, 1914, 2,470,436 tons.

(Data from Lloyd's Register. The Nautical Gazette, Jan. 10, 1925, page 43.)

Total gross tonnage of Merchant Marine throughout world as of July 1, 1923, was 62,335,373 tons.

—(World Almanac for 1924, page 722.)

$$57\% \text{ of } 2,470,436 = 1,408,149 \text{ gross tons}$$

$$1,408,149 \div 62,335,373 = 2\% \text{ of total gross tonnage}$$

APPENDIX L

U. S. NAVY REQUIREMENTS

COAL CONSUMED BY U. S. NAVY

1920	1,590,000 tons
1921	704,000 tons
1922	456,000 tons
1923	355,397 tons

(Annual Reports of the Secretary of the Navy.)

OIL CONSUMED BY U. S. NAVY

(As Officially Reported)

1920	6,714,000 bbls.
1921	7,200,000 bbls.

(Petroleum Year Book, 1922, page 55.)

FUEL CONSUMPTION FROM JAN. 1, TO NOV. 15, 1924

Fuel oil,	5,114,217 bbls.
Diesel oil,	71,244 bbls.
Coal,	355,397 tons.

(Officially reported by Secretary of the Navy.)

$5,114,217 \div .875 = 5,844,819$ bbls. fuel oil for year.

$71,244 \div .875 = 81,193$ bbls. Diesel oil for year.

$355,397 \div .875 = 406,168$ tons coal for year.

APPENDIX M

PUBLIC UTILITY ELECTRIC PLANT REQUIREMENTS

	1920	1921	1922	1923
Total production (thousands of Kw.-hrs.)	43,554,880	40,975,617	47,659,004	55,674,435
Produced by water power	16,149,710	14,970,408	17,206,465	19,347,499
Produced by use of fuels	27,405,170	26,005,209	30,452,539	36,326,936
Consumption of coal (short tons)	37,123,855	31,585,284	34,178,907	38,954,338
Consumption of fuel oil (bbl.)	13,122,704	12,045,409	13,197,216	14,679,205
Gas (M. cu. ft.)	24,702,107	23,721,503	27,172,228	31,433,205
Production by wood (M. Kw.-hrs.)	157,366	141,976	212,596	234,487

(Annual Production of Electric Power and Consumption of Fuels by Public Utility Power Plants in the U. S., U. S. G. S. No. 17,254.)

	1917	1922
Total output sold (M. Kw.-hr.)	25,751,965	41,964,785
Sold for light	5,112,517	9,777,114
Per capita for light	50.0	92.9
Number of customers	7,178,703	12,709,868

(Bureau of Census data, Dept. of Commerce, Statistical Abstract of U. S., 1923, page 245.)

Diesel engines sold to end of 1922: Industrial 400,000 H.P.

Central stations, 25% of industrial installations.

(Diesel Engines, by Morrison, 1923, page 2.)

APPENDIX N

PUBLIC UTILITY ELECTRIC PLANT ENERGY FOR 1924

Total production, kilowatt-hours.....	58,996,000,000
Produced by water power.....	20,005,000,000
Produced by fuels.....	38,991,000,000
Coal consumed (short tons).....	37,483,000
Fuel oil consumed (barrels).....	16,713,000
Gas consumed (M. of cubic feet).....	48,520,000
Power generated by wood (kilowatt hours).....	252,822,000

(Compiled from Monthly Reports of U. S. G. S., on "Production of Electric Power and Consumption of Fuels by Public Utility Power Plants in the U. S.")

APPENDIX O

POTENTIAL WATER POWER OF THE UNITED STATES

Developed H.P., 1921.....	7,926,958
Developed H.P., 1924.....	9,086,958

Distribution of Water Power, 1924:

Public utility plants.....	7,348,197 H.P.—81%
Manufacturing plants.....	1,738,761 H.P.—19%

Potential H.P.:

Available 90% of time.....	34,818,000 H.P.
Available 50% of time.....	55,030,000 H.P.

Total ultimate capacity.....	72,000,000 H.P.
------------------------------	-----------------

(Developed and Potential Water Power of the U. S., 1924. Dept. of the Interior, U. S. G. S. Memorandum for Press, No. L-7115, April 29, 1924.)

APPENDIX P

RAILROAD REQUIREMENTS—(STEAM ROADS)

	1920	1921	1922
Anthracite coal (tons).....	3,861,000	2,644,000	2,473,000
Bituminous coal (tons).....	135,414,000	107,910,000	113,163,000
Fuel oil (gallons).....	1,929,671,000	1,661,444,000	1,828,125,000
Hard wood (cords).....	71,580	48,877	49,991
Soft wood (cords).....	172,564	132,768	110,059

Hard wood—1 cord = $\frac{3}{4}$ ton coal

Soft wood —1 cord = $\frac{1}{2}$ ton coal

(Interstate Commerce Commission data, Statistical Abstracts of U. S., 1921, page 615; 1923, page 410.)

Coal energy equivalent of coal and wood for 1922... 68,073,161,000 H.P. Hr.

Fuel oil energy for 1922..... 6,400,998,000 H.P. Hr.

Total energy for steam roads..... 74,474,159,000 H.P. Hr.

1922 Coal energy, 91%

Fuel oil energy, 9%

APPENDIX Q

INDUSTRIAL REQUIREMENTS—1919

FUEL CONSUMED BY MANUFACTURERS, 1919

Anthracite coal.....	14,557,024 long tons
Bituminous coal.....	203,444,000 short tons
Coke.....	43,561,633 short tons
Fuel oils.....	92,611,186 bbls. (42 gals.)
Gasoline and other volatile oils.....	2,344,469 bbls. (42 gals.)
Gas.....	344,570,711 M. cu. ft.

(Bureau of Census data, Dept. of Commerce Statistical Abstract of U. S., 1923, page 290.)

DIESEL ENERGY

(Distribution of Industrial Installations of Diesel Engines Sold in the U. S. to End of 1922)

Central stations.....	25 %
Electric railways.....	1.7%
Industries.....	73.3%

Diesel Engines Sold to End of 1922 in the United States:

Industrial.....	400,000 H.P.
-----------------	--------------

(Diesel Engines, by Morrison, 1923, page 2.)

HYDRAULIC POWER IN 1924

Public Utility Electric Plants.....	81%
Manufacturing plants.....	19%

(Developed and Potential Water Power of the U. S., 1924. U. S. G. S. Memorandum for Press, April 29, 1924, No. L-7115.)

APPENDIX R

TOTAL ENERGY REQUIREMENTS OF U. S.

	1920	1921	1922	1923	1924
					(Preliminary)
Fuel oil, gas oil and crude petroleum consumed as fuel (millions of barrels).....	274	274	324	395	391
(G. B. Richardson, Statistics of Crude Petroleum for March, 1925.) (U. S. G. S. No. 1283 (1925, No. 3), page 5.)					
Gasoline (millions of barrels).	101	108	128	159	185
(U. S. Bureau of Mines data.)					
Natural gas (billions of cubic feet).....	798	662	763	1008	
(Natural gas in 1923, U. S. G. S. Memorandum for Press, No. 18,061, page 3.)					
Coal retained for domestic consumption (millions of long tons).....	468	549			
(U. S. G. S. data. Statistical Abstract of U. S., 1921, page 606.)					
Hydraulic power, developed horse-power, 1921				7,926,958 H.P.	
“ “ “ “ 1924				9,086,958 H.P.	
(U. S. G. S. data, Developed and Potential Water Power of the U. S., 1924, Memorandum for Press, No. L-7115, April 29, 1924.)					

APPENDIX S

DOMESTIC CONSUMPTION OF FUEL OIL, GAS OIL AND CRUDE OIL USED AS FUEL

(Millions of Barrels)

	1920	1921	1922	1923	1924 (Preliminary)
Indicated domestic consumption of crude petroleum *.....	522	521	585	715	742
Crude oil run to refinery stills.....	<u>434</u>	<u>443</u>	<u>501</u>	<u>581</u>	<u>644</u>
Indicated domestic consumption of crude petroleum for fuel †.....	88	78	84	134	98
Indicated domestic consumption of gas and fuel oils. (Bureau of Mines)*	<u>186</u>	<u>196</u>	<u>240</u>	<u>261</u>	<u>293</u>
Consumption of crude petroleum, gas and fuel oils for fuel.....	274	274	324	395	391

* Production plus imports minus exports plus stocks, including refinery stocks, at beginning of year minus stocks at end of year.

† Includes losses.

(Prepared by G. B. Richardson, of Geological Survey in Statistics of Crude Petroleum for March, 1925, and preceding months. No. 1283 (1925, No. 3), Dept. of Interior, page 5.)

APPENDIX T

OIL SHALE RESERVES OF THE U. S.

Estimates are made from data available from such sources as U. S. Bureau of Mines, U. S. Geological Survey, various State Bureaus of Mines, State University Geologists, Consulting Geologists and private information.

	Oil Shale in 1000 Tons (Short)	Shale Oil in 1000 Bbls. (42 Gals.)
California.....	13,939,200	5,575,680
Colorado.....	113,792,000	40,640,000
Indiana.....	69,696,000	13,939,200
Kentucky.....	90,604,800	28,993,536
Montana.....	6,969,600	1,393,920
Nevada.....	7,219	2,165
Utah.....	92,159,000	16,588,620
Wyoming.....	7,176,000	1,291,680
Totals.....	394,343,819	108,424,801

(Report of Supply Group of "Committee of Eleven" of American Petroleum Institute, 1925.)

APPENDIX U

SOFT COAL AND LIGNITE RESERVES OF THE U. S.

Estimates of the soft coal and lignite in the ground are based on the conclusions of the International Geological Congress in Ottawa in 1913.

SOFT COAL

	In Thousands of Tons	
	To 3000 Ft.	To 6000 Ft.
Coal Reserves:		
Semi-bituminous	45,660,000	45,660,000
Bituminous	1,428,700,000	1,650,900,000
Sub-bituminous	986,900,000	1,431,300,000
Total	2,461,260,000	3,127,860,000

Possible Total Liquid Products

	In Thousands of 42-Gal. Barrels	
	Estimated Maximum	Estimated Commercial
Semi-bituminous	17,400,000	9,200,000
Bituminous	1,260,000,000	304,400,000
Sub-bituminous	818,000,000	211,400,000
Total	2,095,400,000	525,000,000

Possible Light Motor Fuel

	In Thousands of 42-Gal. Barrels	
	Estimated Maximum	Estimated Commercial
Semi-bituminous.....	4,340,000	1,600,000
Bituminous.....	252,000,000	53,300,000
Sub-bituminous.....	136,300,000	37,000,000
Total.....	392,640,000	91,900,000

LIGNITE

Lignite reserves (thousands of tons).....	986,000,000
Possible total liquid products (M. 42-gal. barrels).....	70,500,000
Possible light motor fuel (M. 42-gal. barrels).....	11,700,000

(Report of Supply Group of "Committee of Eleven" of American Petroleum Institute, 1925.)

APPENDIX V

MOTOR FUEL FROM COAL

(Excerpt from A Critical Analysis of the Future Demand for Gasoline and Lubricating Oils for Automotive Uses, by H. L. HORNING, *President, Society of Automotive Engineers.*)

. . . coal is the most promising of all our sources of raw material. By this I do not expect the well known aromatics derived in the usual distillation to be the source of coal fuels, but on the contrary, I expect developments in chemistry within the next decade to show us how to convert coal directly into motor fuels as primary products and with valuable by-products. There probably exists today suppressed, known, or awaiting developments, facts which constitute the very basis for this great step. I am absolutely certain that Organic Chemistry could solve this in little time. When these changes will come about depends on economic causes and not for want of scientific ability. Economic changes will always lag way behind scientific achievement.

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